MANITOBA CANADA CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

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CREDA

Canada

MANITOBA

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# THE FEASIBILITY OF CONVERSION TO NON-PETROLEUM POWER SOURCES

## — FINAL REPORT —

# MANITOBA/CANADA CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

The availability of secure and affordable energy supplies is a subject of national concern. It is an accepted fact that our primary energy sources - oil and natural gas - are becoming less accessible and more costly. However, Canada is well-endowed with non-renewable and alternative resources that can provide a bridge into the future.

To this end, the governments of Manitoba and Canada have entered into a Conservation and Renewable Energy Demonstration Agreement which was signed May 9, 1980 and terminates March 31, 1984. The Agreement is dedicated to the development and demonstration of conservation and renewable energy technologies. Equally cost-shared by the provincial and federal governments, the program has a total budget of $18-million.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- To develop broad public awareness of the potential of renewable energy and conservation technology.
- To provide opportunities for the commercial application of the technologies within Manitoba.
- To create economic spin-off benefits for manufacturing, industry and commerce.
- To create employment in new or existing energy-related industries.

## EXECUTIVE SUMMARY

In the Spring of 1981, the City of Winnipeg, with the cooperation and support of the Province of Manitoba and the Federal Government, initiated a study to assess the feasibility of converting all or part of the Winnipeg Transit System to non-petroleum sources. Funding for the study was provided under the Manitoba/Canada Conservation and Renewable Energy Demonstration Agreement (CREDA).

In common with many other transit systems in North America, the Winnipeg Transit System is dependent upon petroleum-based fuels for motive power; all of its vehicles are powered by diesel or gasoline engines. Concerns about the future availability and price of petroleum fuels have created interest in alternative energy sources.

Unlike most other jurisdictions, the Province of Manitoba has a large reserve of untapped hydraulic resources which can be used to generate electric power. A program of construction of major hydro-electric power projects has been developed. It was therefore considered appropriate to emphasize electric power options in the investigation of potential alternatives to petroleum-based fuels.

### THE STUDY PROCESS

The study involved a number of major steps:

- Study Design: including establishment of final study objectives, work program and organization;
- Technology Review: an assessment of transit vehicles using alternative fuels, electrical propulsion, energy storage devices, and combinations thereof, in comparison with the standard diesel bus;

- Future Transportation Requirements: a review of likely demand for future transit services in Winnipeg, and maximum loadings in major corridors, under various conditions of social and economic trends, transit service levels, and price/availability of automotive fuels;

- Future Energy Prices: an investigation of possible future prices for diesel fuel, electricity and alternative automotive fuels;

- Preliminary Screening: narrowing the range of possibilities by subjecting the technologies to a preliminary screening in terms of their availability and appropriateness for Winnipeg;

- Alternative Transit Systems: investigation of possible combinations of bus and trolley coach routes, developed into four system alternatives;

- Cost Comparisons: the analysis of costs per kilometre of operating various types of vehicles and comparisons of total annual costs for alternative systems, including capital, maintenance and energy costs under current and future energy prices;

- Evaluation and Recommendations: an assessment of the costs and likely benefits of alternative systems/approaches, and recommendations for consideration by the City of Winnipeg.

## RESULTS AND RECOMMENDATIONS:

Numerous combinations of various fuels, engine types and vehicle types were considered, including hybrid forms of motive power, such as diesel/electric and flywheels, and other regenerative braking systems.

Of the options, three were considered most appropriate for detailed economic comparison with conventional diesel traction. These were electric trolley coach, trolley coach/diesel hybrid and trolley coach with flywheel.

The economic analysis revealed that a system of standard trolley coaches was the best alternative to diesel, given the specific route structure and operating conditions in Winnipeg and taking into consideration projected increases in diesel costs relative to electricity. Based on current and projected ridership trends, a network consisting of three specific routes was recommended for an initial trolley coach system.

## SUMMARY OF FINDINGS AND RECOMMENDATIONS:

1. Winnipeg should adopt as a conditional goal the implementation of a trolley coach system. This should be on the basis of the initial system developed in the study (Osborne/Selkirk, Corydon/North Main, and East Kildonan/ Portage (Polo Park) routes, and perhaps also including the Southwest Transit Corridor routes), recognizing that the disignation of routes may change if growth patterns are different than presently expected.

   Sensitivity analyses indicated that a trolley coach system would be more economic than diesel under the following circumstances:

   - with a 20% capital subsidy, current ridership levels and fuel costs;
   - with a 10% capital subsidy and either an increase in the number of vehicles required to serve these routes to 115 vehicles (representing a 12% increase in ridership) or a diesel fuel price increase to between 39¢ and 42¢ per litre with the present level of patronage and of service;

. with no capital subsidy but with a fuel price increase to 39¢ per litre and a growth in ridership that would require 120 vehicles in service on these routes;

2. The necessary capital funding for the project should be included in the City's five year capital program. The estimated cost of implementation is $40-million. (This includes $25-million for vehicles and $15-million for fixed installations, expressed in 1981 dollars). Construction is presently projected to begin in 1985 with completion in 1987. The vehicle capital costs would be offset by approximately $17-million in diesel vehicle purchases which would not be necessary if trolley coaches are purchased. Because of the difference in the expected economic lives of the two types of vehicles the effective annual costs of the two types would be very similar. If capital assistance were provided, the effective annual costs of the trolley coaches would be less than that for diesel buses.

3. Potential sources of capital subsidy should be explored. These might include the Provincial Government which is interested in the development of hydro-electric resources of northern Manitoba and the Federal Government which has set a precedent in providing capital subsidies for the conversion of automobiles to alternative sources of fuel.

4. The growth in transit ridership and fuel prices should be monitored closely to determine when these systems become cost-effective. Developments may advance or retard the time when the introduction of trolley coach service is economic.

5. Physical planning should begin in terms of electricity supply and other needs to ensure that the implementation of the system will be made as easy and as inexpensive as possible. Items that could be considered would be the reservation of sites for substations, the possible adoption of lamp standards and utility poles suitable for future installation of trolley coach overheads and other functions of the City and Winnipeg Hydro.

6. Discussions should begin on the approach to be taken with respect to electrical power pricing and the construction and maintenance of the electrical systems. Both Winnipeg Hydro and Manitoba Hydro should be contacted to discuss electrical pricing. For example, it may be possible that Manitoba Hydro would wish to develop a base load for its new hydro-electric projects and would consider providing electrical power to Winnipeg Transit under a different rate structure than that currently used for industrial users.

7. Discussions should begin with engine manufacturers to explore the possibility of producing an alcohol-fueled bus engine. The economics of the production of the alcohol fuel should be investigated in more detail, particularly its production from municipal wastes. It might be more appropriate for the Provincial or Federal Governments to undertake these investigations than for Winnipeg Transit to take the lead.

8. Winnipeg Transit should monitor developments in transit technology over the coming years. This would include progress with vehicles such as the trolley/flywheel, the trolley/diesel, buses fueled with compressed natural gas, and the diesel or alcohol-fueled vehicle with on-board energy storage through hydraulic accumulators, batteries or flywheels.

9. Winnipeg Transit and other departments of the City of Winnipeg should develop a process to make the critical decisions on the implementation of the proposed trolley coach system. The process includes the monitoring of developments as described above and the establishment of a mechanism to make the necessary decisions in a timely manner.

## RÉSUMÉ ADMINISTRATIF

Grâce à la coopération et à l'appui de la province du Manitoba et du gouvernement fédéral, la ville de Winnipeg entreprenait au printemps 1981 une étude sur les possibilités d'adapter la totalité ou une partie du Réseau de transport en commun de Winnipeg à l'utilisation de produits non pétroliers. Cette étude était financée par le Programme Manitoba-Canada de démonstration des énergies renouvelables et des économies d'énergie (PDEREE).

A l'instar de bien d'autres sociétés de transports en commun d'Amérique du Nord, le Réseau de transports en commun de Winnipeg a recours aux produits pétroliers comme carburants; tous ses véhicules ont des moteurs Diesel ou des moteurs à essence. Les inquiétudes créées par les ressources futures et par le prix de l'essence ont suscité de l'intérêt vis-à-vis des sources d'énergie de remplacement.

Le Manitoba diffère des autres provinces dans la mesure où il s'y trouve de vastes ressources hydrauliques inexploitées qui peuvent servir à produire de l'électricité. On a mis sur pied un programme de construction de puissantes centrales hydroélectriques. On a donc considéré qu'il était approprié de mettre l'accent sur l'usage de l'électricité dans l'analyse des sources d'énergie susceptibles de remplacer les produits pétroliers.

### LES MÉTHODES D'ÉTUDES

Cette étude comportait plusieurs étapes importantes, à savoir:

- **Planification de l'étude:** comprenant la définition des objectifs finals, le programme et l'organisation du travail;

- **Étude technologique:** évaluation des véhicules de transport en commun utilisant les carburants de remplacement, l'électricité, les systèmes d'accumulation d'énergie et toute combinaison de ces moyens, par rapport aux autobus Diesel ordinaires;

- **Évaluation des transports en commun:** étude de l'accroissement probable des services de transport en commun requis à Winnipeg et des capacités maximales dans les artères principales, compte tenu des diverses tendances sociales et économiques, des niveaux d'utilisation des transports en commun, du prix et de la disponibilité des carburants;

- **Le prix futur de l'énergie:** une étude des futurs prix probables du carburant pour véhicules Diesel, de l'électricité et des carburants de remplacement;

- **Sélection préalable:** réduire le nombre des possibilités grâce à une sélection préalable des technologies en fonction de leur disponibilité et de leur caractère approprié à Winnipeg;

- **Autres systèmes de transport en commun:** examen des possibilités d'établir des itinéraires combinant l'emploi des autobus ordinaires et des autobus à trolley et résultant en quatre systèmes possibles;

- **Comparaison du coût:** examen du coût par kilomètre pour chaque catégorie de véhicules et comparaison du coût annuel des systèmes de remplacement, y compris le capital, l'entretien et le coût de l'énergie selon les prix actuels et futurs.

- **Évaluation et recommandations:** une estimation des coûts et des profits probables des systèmes et des moyens de remplacement ainsi que des recommandations à l'intention de la Ville de Winnipeg.

## RÉSULTATS ET RECOMMANDATIONS:

On envisagea de nombreuses combinaisons de carburants variés, de types de moteurs et de types de véhicules, y compris les formes mixtes de force motrice comme les véhicules combinés Diesel-électriques et à volants d'inertie et autres systèmes à freins régénérateurs.

Trois des options furent considérées comme se prêtant le mieux à une comparaison économique détaillée avec les moteurs Diesel ordinaires. Il s'agissait de trolleybus, de véhicules mixtes trolleybus-Diesel et de trolleybus avec volants d'inertie.

Il ressortit de l'analyse économique qu'un système de trolleybus ordinaires remplacerait le plus avantageusement les véhicules Diesel, compte tenu de la structure des réseaux et des conditions de fonctionnement particulières à Winnipeg ainsi que des augmentations projetées des prix du carburant diesel par rapport à l'électricité. En se basant sur les tendances actuelles et futures des voyageurs, il fut recommandé d'établir un réseau de trois itinéraires donnés utilisant le premier système de trolleybus.

## SOMMAIRE DES RÉSULTATS ET DES RECOMMANDATIONS:

1. La ville de Winnipeg devrait se donner pour objectif conditionnel de créer un système de trolleybus tel qu'il est proposé dans l'étude, c'est-à-dire comprenant les itinéraires Osborne-Selkirk, Corydon-North Main et East Kildonan-Portage (Polo Park) et englobant peut-être les itinéraires principaux du sud sans écarter la possiblité de choisir d'autres itinéraires si les conditions de développement variaient de celles qu'on prévoit aujourd'hui.

   Les études circonstanciées font ressortir que dans les conditions suivantes un système de trolleybus serait plus économique qu'un système de véhicules Diesel:

   . avec 20% des captitaux subventionnés tandis que le nombre actuel de voyageurs et le prix des carburant restent constants;

- avec 10% des capitaux subventionnés tandis que le nombre de véhicules augmente jusqu'à 115 (soit une augmentation de 12% du nombre de voyageurs) ou bien le prix du carburant diesel augmente jusqu'à 39 ou 42 cents par litre et le nombre de voyageurs et les services restent constants.

- sans capitaux subventionnés mais si le prix du carburant augmente jusqu'à 39 cents par litre et l'augmentation du nombre de voyageurs exige l'emploi de 120 véhicules sur ces itinéraires.

2. Le financement nécessaire des capitaux du projet devrait faire partie du programme quiquennal d'immobilisation de la ville. On estime que le coût du projet calculé en dollars de 1981 serait de 40 millions de dollars. (c'est-à-dire 25 millions pour les véhicules et 15 millions pour les installations permanentes.) On prévoit actuellement que la construction commencera en 1985 pour se terminer en 1987. Si on achetait les trolleybus, le coût en capital serait contrebalancé par l'inutilité d'acheter pour environ 17 millions de véhicules Diesel. Comme sur le plan économique la durée des deux types de véhicules varie, les coûts réels annuels seraient assez semblables pour chacun d'eux. Si l'on obtenait une subvention en immobilisations, les coûts réels annuels des trolleybus seraient inférieurs à ceux des autobus Diesel.

3. On devrait explorer les sources possibles de subventions en immobilisations. On pourrait penser au gouvernement provincial qui s'intéresse au développement des ressources hydro-électriques du nord du Manitoba et au gouvernement fédéral qui a déjà créé un précédent en accordant des subventions en immobilisations afin de permettre la transformation des automobiles pour la consommation des carburants de remplacement.

4. L'augmentation du nombre d'usagers des transports en commun et l'augmentation des prix des carburants devraient être examinés de près afin que l'on sache quand ces systèmes deviennent profitables. Des variations pourraient avancer ou retarder le moment où il sera économique d'utiliser les trolleybus.

5. Au point de vue pratique, la planification devrait commencer au niveau des réserves d'électricité et des autres besoins afin que la mise en place du système soit faite aussi facilement et aussi économiquement que possible. Il faudrait considérer certaines choses comme la réservation des emplacements des sous-stations, le choix possible de pylônes de suspension des lampes d'éclairage et des pylônes de suspension des câbles électriques qui pourraient servir aux installations futures des trolleys et à d'autres usages de la Ville et d'Hydro-Winnipeg.

6. Des entretiens devraient commencer en ce qui concerne le prix du courant électrique et la construction et l'entretien des systèmes électriques. Il faudrait se mettre en rapport avec Hydro-Winnipeg et Hydro-Manitoba pour discuter des prix. Il est possible, par exemple, que Hydro-Manitoba décide de fixer une capacité de charge pour ses nouvelles centrales électriques et accepte de distribuer le courant à Winnipeg au Réseau de transport en commun de Winnipeg à des tarifs différents de ceux qui sont accordés aux consommateurs industriels.

7. Des entretiens devraient commencer avec les constructeurs de moteurs afin d'étudier la possibilité de construire des moteurs d'autobus utilisant l'alcool comme carburant. Il faudrait examiner de plus près les aspects économiques de la production de l'alcool comme carburant, en particulier lorsqu'il s'agit d'alcool fabriqué à partir des déchets municipaux. Il paraît préférable de laisser les gouvernements provincial et fédéral diriger ces recherches plutôt que d'en laisser l'initiative au Réseau de transport en commun de Winnipeg.

8. Au cours des années à venir, le Réseau de transport en commun de Winnipeg devrait étudier les progrès réalisés dans le domaine de la technologie des transports en commun et s'appliquant aux véhicules suivants: les trolleybus avec volants d'inertie, les combinés trolleybus et Diesel, les autobus à gaz naturel comprimé, les véhicules Diesel ou les véhicules à alcool qui emmagasinent l'énergie au moyen d'accumulateurs hydrauliques, de batteries ou de volants d'inertie.

9. Le Réseau de transport en commun de Winnipeg et d'autres services de la Ville devraient créer un système pour prendre des décisions importantes relatives à l'organisation du réseau proposé de trolleybus. Ce système devrait comprendre l'étude des éléments décrits ci-dessus et l'établissement d'un processus pour prendre des décisions au moment opportun.

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# 1. INTRODUCTION

In common with many other transit systems in North America and in the world, the Winnipeg Transit system is dependent upon petroleum-based fuels for motive power; all of its vehicles are powered by diesel or gasoline engines. Concerns about the future availability and price of petroleum fuels have created interest in alternative sources of energy.

In the Spring of 1981, the City of Winnipeg, with the cooperation of the Province of Manitoba and the Federal Government, decided to undertake a study of the feasibility of converting all or part of the Winnipeg Transit system to non-petroleum sources. Unlike most other jurisdictions, the Province of Manitoba has a large reserve of untapped hydraulic resources which can be used to generate electric power. A program of construction of major hydro-electric power projects has been developed. It was therefore considered appropriate to emphasize electric power options in the investigation of potential alternatives to petroleum based fuels.

## OBJECTIVES

The objectives of the study, as defined in the Terms of Reference, were as follows:

"1. To assess Winnipeg Transit's existing and future energy position.

2. To identify energy options for Winnipeg Transit with particular emphasis on hydro electric alternatives and to assess the validity of these alternatives.

3. To develop an alternative energy plan for Winnipeg Transit and an appropriate staging plan for implementation."

## METHODOLOGY AND ORGANIZATION

The methodology used in this report was, after exploring the future energy and passenger ridership environment, to array the potential technolo-

gical alternatives to diesel propulsion. These alternatives were then put through a number of screenings to select those most suitable for implementation in Winnipeg. The surviving alternatives were then examined in more detail and recommendations for action developed.

The report itself is organized in ten chapters as follows:

1. Introduction - A presentation of the background and objectives of the study,

2. Energy Pricing and Availability - An exploration of the future prices and availability of fuels, concentrating on petroleum-based fuels but also examining some of the potential alternatives.

3. Future Transportation Requirements - Examination of the potential changes in ridership on the Winnipeg Transit System up to 1999 based on an analysis of future land use and transportation plans and the possible effects of petroleum fuel price increases.

4. Potential Technologies - An examination of the technologies potentially available to Winnipeg Transit including a description of each and a tabulation of their most relevant characteristics.

5. Screening of Alternatives - An initial screening of the alternatives to select those most suitable for Winnipeg based on an evaluation of their status of technological development, their potential cost, and their general suitability. Two types of alternatives are selected for further evaluation; electric traction options (trolley coach, trolley/diesel and trolley/flywheel) and liquid fuel options (alcohol, propane, diesel/alcohol and diesel/hydraulic accumulator).

6. Electric Traction Options - The electric options are examined in terms of capital and operating costs in the context of 1999 expected ridership.

7. Liquid Fuel Options - The liquid fuel options are examined in terms of the promise of each technology, the amount of development to be done and the future availability and price of fuels.

8. Evaluation of Alternative - An overall evaluation of the options, resulting in the selection of a conventional trolley coach system as having the greatest potential.

9. Initial System - Based upon the expected viability of the trolley coach system, initial trolley coach systems are investigated. The necessary conditions for implementation are explored in terms of both ridership increases that might be required and fuel price increases that might be necessary to make them economically viable.

10. Conclusions and Recommendations - A summary of this report is also available, separately bound.

## 2. ENERGY PRICING AND AVAILABILITY

In this chapter the future availability and pricing of alternative fuels is explored as well as the potential impacts of petroleum fuel shortfalls on Winnipeg Transit's operations.

### DIESEL FUEL AND GASOLINE SUPPLY AND PRICING

The major source of information for this comes from the National Energy Program (NEP) published by the Federal Government in October, 1980, and subsequent updates and modifications such as introduced by the energy pricing agreements between the Federal and Provincial Governments in September, 1981.

The principal objectives of the National Energy Program are to restructure Canada's energy system to balance domestic oil supplies with domestic demand by 1990, to achieve an equitable sharing of energy benefits and burdens, to promote a higher level of Canadian ownership and control of the energy sector and to expand the role of the public sector in oil and gas. The implementation of these objectives requires the substitution of petroleum consumption with other fuels, primarily natural gas and propane, and conservation measures to reduce demand. The program forecasts that petroleum consumption will be in balance with domestic production by 1990. It requires an increased price schedule for conventional oil and higher base prices for oil from tar sands and from tertiary recovery methods.

#### Crude Oil Prices

Since the publication of the National Energy Program in October, 1980, the Federal Government has authorized an additional levy to allow Petro Canada to purchase Petrofina. The price projections were also substantially modified by the Alberta/Federal oil and natural gas pricing agreement announced in September, 1981 and similar agreements with other provinces. This agreement included the following provision for price increases for "old" conventional crude oil (discovered before January, 1981):

- $2 50 per barrel increase October 1, 1981;

- $2.25 per barrel increase January 1, 1982;
- $2.25 per barrel increase July 1, 1982;
- $4.00 per barrel increase each six months (January 1 & July 1) from 1983 through 1986.

This will add $39.00 to the current conventional crude price by July 1, 1986, excluding changes in the petroleum compensation charge, Canadianization levy and transportation costs. The increases are subject to the limit that they should not increase Canadian prices above 75% of the world oil price.

As of July 1, 1981 the cost structure for domestic crude was approximately as follows:

| | |
|---|---|
| - conventional oil weighted average wellhead price | $18.75 per barrel |
| - petroleum compensation charge | 6.30 |
| - Canadianization levy | 1.15 |
| - transport to Winnipeg | .60 |
| - blended price excluding the temporary levy to compensate for the Alberta cut-backs | $26.80 |

As described, this price does not include the temporary Federal levy imposed to subsidize additional imports made necessary by the Alberta cut-backs in production in the summer of 1981.

The Winnipeg price increased to $29.30 as at October 1, 1981 ($26.80 plus $2.50). Further increases are expected as the price of conventional and non-conventional oil increase and as the proportions of each change. The resulting expected Manitoba blended prices in current dollars are shown below:

- October 1, 1981 $29.30
- January 1, 1986 $64.10
- July 1, 1986 $68.10

Extrapolating these price forecasts beyond 1986 at $8.00 per barrel increase per year and 5¢ per year per barrel increase in transportation results in the following future prices:

- July 1, 1990 $100.30
- July 1, 1999 $172.75

It must be emphasized that these extrapolations can only be guesses at this stage, since the Alberta/Federal agreement applies only to 1986 and prices beyond that date are subject to future negotiations.

At an annual inflation rate of 10%, from October 1, 1981, the Manitoba blended price would be almost $62.00 at July 1, 1990, compared with $100.30 under the revised agreement. This means that the extrapolation of crude oil prices implies an increase of over 60% in real terms between 1981 and 1990. The maximum increase actually occurs in 1988 where the comparison between the extrapolated price and the inflated price implies a price increase in real terms of 65%. Projecting the 10% per year increased from October, 1981 to July, 1999 results in a crude oil price of $160 per barrel. The extrapolation of increases based on the Canada/Alberta agreement results in a price of $173, implying a subsequent reduction in the real price of crude oil if the 10% inflation rate actually occurs. Obviously these extrapolations and projections lead one on to shifting ground. The implication remains, however, that the real price of crude oil may increase by over 60% over the coming decade.

It should be mentioned that, despite real increases in the international price of oil in the past two years, the expectation of many energy analysts is that over the next few years there will be an oversupply of oil, leading to downward pressure on the price. A decrease or relative stability of international oil prices will affect Canadian prices in two ways. Most immediately they will decrease the petroleum compensation charge which is levied on domestic production to subsidize the import of foreign crude. They

would also impact Canadian prices by limiting the extent to which the prices are increased. The Canada/Alberta Agreement had a maximum price level within Canada of 75% of the international oil prices.

The future of oil prices is very uncertain, as has been shown in this section. It can be seen from the foregoing, however, that it would be prudent to plan for significant increases in the price of domestic crude, perhaps up to the order of a 50% increase (in 1981 dollars).

## Diesel Fuel Price Projections

The NEP projections described in the previous section were used to estimate future diesel fuel prices. The price for diesel fuel includes several other elements beyond the crude price of the petroleum consumed. These include the Federal Excise Tax, the cost for distribution, refining and marketing and Provincial road tax. The taxes were assumed to be levied at a constant rate although, because of increases in the base on which they are levied, they would increase in magnitude. The other costs were assumed to increase at 10% per year.

As can be seen from Exhibit 2.1, based upon the NEP, the price to Winnipeg Transit is expected to increase substantially over current values. When discounted to 1981 dollars, however, the maximum increase is approximately 33%. This occurs in 1988. Because crude oil price increases were assumed to be a constant amount each year, they represent a smaller percentage increase each year; assuming a continuous inflation rate of 10% per year, the price expressed in constant dollars appears to fall after 1988. This is a peculiarity of the projection methodology and is considered to be unlikely.

In subsequent chapters of this study the range of diesel fuel prices used in evaluations was between $0.33 per litre (called the current fuel prices as this will be the price in early 1982) and the "future" fuel price of $0.45 per litre in 1981 dollars which represents a 36% increase in the price of diesel fuel. The viability of alternatives were evaluated over this range of increases. The $0.45 per litre price is to some extent arbitrary but represents a possible increase in diesel prices over the coming two decades.

## exhibit 2.1

## Diesel Fuel Cost Projection

| DATE | MANITOBA BLENDED CRUDE PRICE ($ per barrel) | MANITOBA CRUDE PRICE (¢ per litre) | FEDERAL TAX AT 13.5% OF CRUDE COST (¢ per litre) | NON-CRUDE COST* (¢ per litre) | PROVINCIAL ROAD TAX AT 20% OF COST (¢ per litre) | RETAIL PRICE (¢ per litre) | WINNIPEG TRANSIT PRICE** (¢ per litre) | PRICE IN CONSTANT 1981 DOLLARS+ (¢ per litre) |
|---|---|---|---|---|---|---|---|---|
| Oct. 1, 1981 | 29.30 | 18.4 | 2.5 | 8.7 | 5.9 | 35.5 | 31.9 | 31.9 |
| July 1, 1986 | 68.10 | 42.8 | 5.8 | 13.7 | 12.5 | 74.7 | 67.2 | 41.8 |
| July 1, 1987 | 76.15 | 47.9 | 6.5 | 15.0 | 13.9 | 83.2 | 74.9 | 42.3 |
| July 1, 1988 | 84.20 | 52.9 | 7.1 | 16.6 | 15.3 | 91.9 | 82.7 | 42.5 |
| July 1, 1989 | 92.35 | 58.0 | 7.8 | 18.2 | 16.8 | 100.8 | 90.7 | 42.3++ |
| July 1, 1990 | 100.30 | 63.0 | 8.5 | 20.0 | 18.3 | 109.9 | 98.9 | 41.9++ |

NOTES:
* Non-crude costs include costs for pipeline, refining, and market activity and were increased at the rate of 10% per annum.
** Winnipeg Transit currently receives approximately a 12% discount on fuel purchases and this was assumed to continue in the future. The numbers in this column represent 88% of the price before road tax plus the Provincial Road Tax.
\+ Current dollars were discounted to 1981 on the basis of a 10% per annum inflation rate.
++ As explained in the text the price in constant dollars is unlikely to decrease.

## POTENTIAL FOR FUEL SCARCITIES

Approximately 30% of Canada's current crude oil supply currently comes from foreign sources. As has been demonstrated by events over the past eight years, the oil supply market is highly unstable and highly sensitive to international political events. As a reflection of concern about general or selective cuts in oil supply, the OECD countries formed the International Energy Agency to monitor crude oil supply and demand and, in the event of a reduction in supply of more than 7% to an individual country or in total, to allocate supplies from a common pool.

In addition, the Federal Government has established the Energy Supplies Allocation Board (ESAB) whose purpose is to develop a contingency plan for the allocation of crude oil if aggregate demand exceeds supply, and to reallocate petroleum products according to priorities of need. The legislation setting up ESAB was part of the Energy Supplies Emergency Act, 1979. The proposed program of allocating priorities was published in the Canada Gazette on November 8, 1980. It is this program which ESAB is currently using to establish priorities and to test the impact of shortfalls on the users of petroleum products.

Three levels of priority are established: A, B and C. The highest priority uses, A, include public transportation (road, rail, water). Discussions with staff of ESAB have indicated that they have planned for crude oil shortfalls up to 15% of current domestic demand, or approximately 50% of foreign supply. ESAB staff do not think it likely that more than 50% of foreign supply would be cut off. Under their allocation program this level of shortfall would not reduce the fuel supply to priority A users. In addition, it is possible for a priority A user to request additional supplies, such as would be the case with Winnipeg Transit in the event of a sharply increased demand for service during a gasoline rationing period. Three levels of approval would be in effect:

1. The supplier of the fuel could automatically allocate additional monthly supplies to the user, up to a pre-specified amount, with a requirement to notify the Provincial ESAB office.

2. The Provincial ESAB office could authorize a further increased supply, again subject to defined limits and with subsequent notification to the National ESAB agency.

3. The National ESAB agency could authorize supply increases above the authority of the Provincial office, subject to demonstrated need.

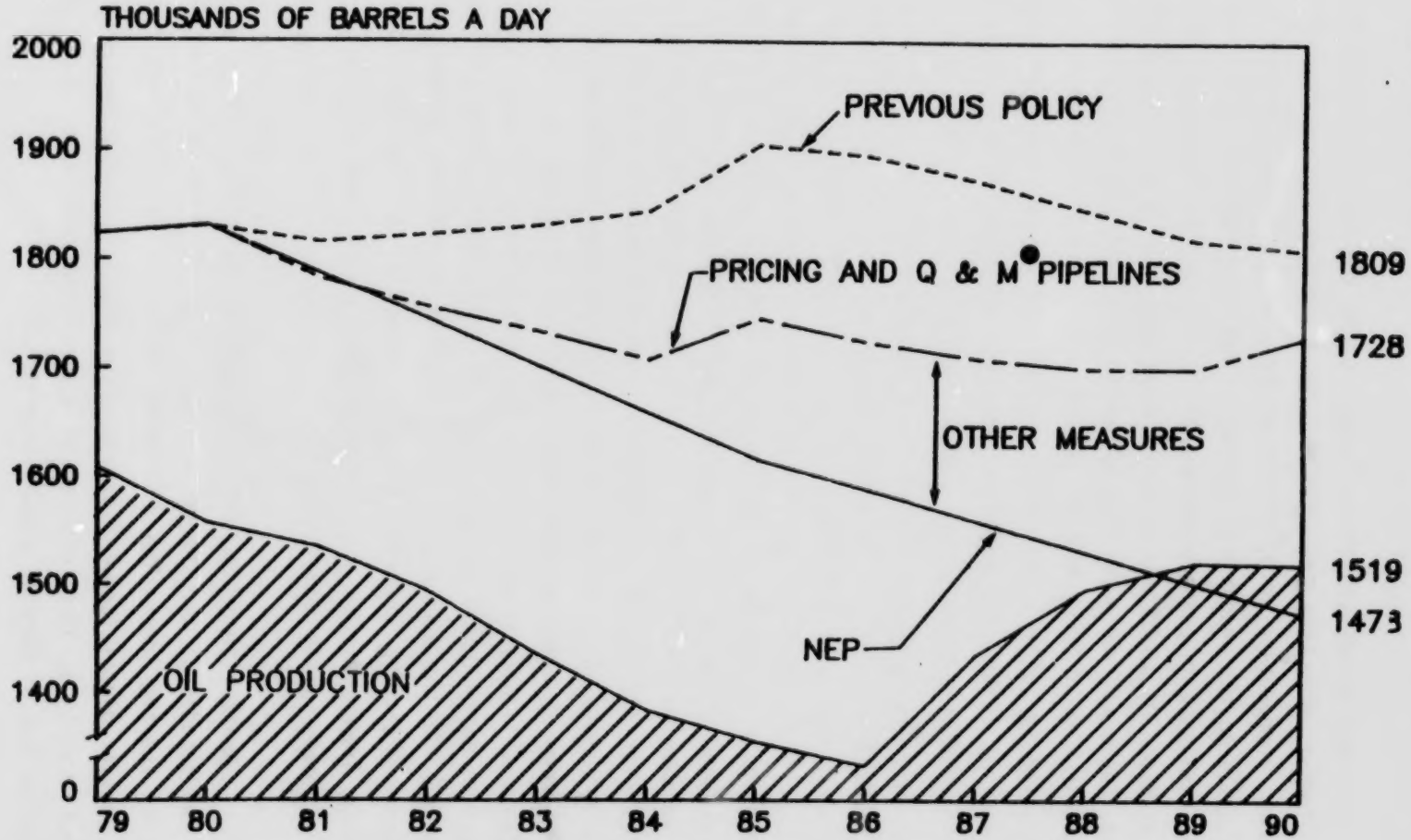
It is the intention of the ESAB offices to make decisions on increased supply within 24 hours of request. They have also indicated that they would be favourably disposed toward increasing the supply to public transit to offset increased service demands generated by rationing of supply to the private automobile (which is in priority category C).

Exhibit 2.2 shows the suggested effects of the NEP policy on Canadian oil demand and supply. Oil production is shown to decrease from a current level of about 1.6 million barrels per day to less than 1.4 million barrels per day in 1986, and rise thereafter to about 1.5 million barrels per day in 1990. The increased supply after 1986 results from an assumed major increase in the production of synthetic crude from tar sands plants and upgrading heavy crude oils. The difference between supply and demand has to be made up by imports; since Canada exports heavy crude and petroleum products, the actual import of foreign crude is approximately twice the amount shown on this diagram. Pricing to encourage conservation, as well as the Quebec and Maritimes natural gas pipeline for this substitute fuel, plus other measures to encourage off-oil programs, are shown to bring supply and demand into balance by 1990.

It can be seen that over the next decade net imports of crude oil are not expected to increase. In the latter half of the decade the reliance on foreign crude is expected to decrease. Thus it does not appear likely that more than a 15% short-fall should have to be faced.

**exhibit 2.2**

**Effects of NEP Policy Elements on Canadian Oil Demand and Supply Balances**




Source: Supplementary Information on Supply/Demand, National Energy Program, January, 1981

● Q & M gas pipeline to serve Maritime Provinces

This discussion has referred to the availability of crude oil. One other factor affecting the availability of high-quality diesel fuel is the different composition of synthetic crudes, as compared with the light crude which has been the traditional source of refinery supply. It is expected that diesel fuel used in transportation will grow steadily throughout the decade to 1990 at about 4% to 5% per annum. Concurrent with the growth in diesel fuel demand, there will be a decline in demand for light grades of heating oil, due to substitution of this fuel by natural gas. Heating oil cannot directly be substituted for diesel fuel without expensive upgrading. There may be some shortages of diesel fuel while refinery equipment is being modified to reflect changing market demand.

**Summary**

There could well be an interruption to the supply of foreign crude oil available in Canada. The impact which such a supply interruption would have depends of course on the extent and length of the supply interruption. It also depends on the extent to which domestic demand for crude oil can be reduced over the decade by measures such as are envisaged in the National Energy Program. At a 50% reduction in foreign supply, the current procedures of ESAB seem to indicate that Winnipeg Transit would obtain not only the current rate of supply of diesel fuel, but would have available increased supply of fuel as necessitated by demand for increased service during periods of fuel rationing. To the extent that these measures do not work as well as currently planned or that a greater than 50% reduction in foreign supply occurs, Winnipeg Transit could experience a shortage during periods of prolonged foreign crude supply interruptions.

Another important factor in considering diesel fuel supply over the next two decades is the change in composition of crude being processed by refineries and the increasing difficulty of producing sufficient quantities of high quality diesel fuel. Since imported crude is predominantly of the light conventional type, this problem of appropriate supply would be exacerbated during periods of foreign supply interruption.

## SUPPLY AND PRICE OF PROPANE

Propane is a hydrocarbon fuel derived principally from the processing of natural gas (80% of current supply comes from natural gas and 20% from crude oil refining). Propane is an ideal transportation fuel for light and medium weight vehicles (up to 20,000 lbs. GVW) and can be readily substituted for gasoline with minor modifications to a gasoline engine. Above this weight, the efficiency of the diesel engine makes it more economically attractive than a propane engine.

Approximately 125,000 barrels of propane are produced daily in Canada, of which about half are exported and half used for domestic consumption. The domestic uses include home heating, industrial, commercial and farm, with some propane being used as a transportation fuel. The other non-transportation, more traditional uses of propane are generally declining, due to substitution by natural gas. The level of supply is expected to remain relatively constant over the next 20 years bringing about continued surpluses. Because of the expected continuing Canadian supply, the Federal Government and some Provinces have specific programs to encourage the use of propane fuel as a substitute for gasoline.

Currently propane fuel costs approximately 70% of the price of gasoline on an energy equivalent basis. Propane fuel has approximately 25% less heat energy per unit volume than gasoline but, because it enters the combustion chamber as a dry gas, it achieves a more complete combustion and therefore is more efficient.

Currently, the retail price of propane as a transportation fuel would be approximately 60% of the pump price for regular leaded gasoline. Future prices of propane will reflect the demand versus supply for this fuel, both domestically and on the world wide market. For purposes of this study,

it is recommended that a price 40% less than the price of gasoline per litre be used. This reflects the likely future pressure to maintain the price differential with respect to gasoline and the reduced energy density of the fuel in comparison with gasoline.

## SUPPLY AND PRICE OF NATURAL GAS

Natural gas is also a very suitable transportation fuel, with a high octane rating and the advantages that accrue to a gaseous fuel. These advantages include more complete combustion (and therefore a higher recovery of the energy content in the fuel), lower emissions, lower maintenance costs and longer engine life. The problem associated with natural gas is that it has to be stored at relatively higher pressure than propane (which is normally stored at 200 psi), and because its low energy density requires significantly more storage volume on-board the vehicle. For an urban transit bus operating approximately 320 km or 200 miles on a 22 hour shift, approximately six times the volume of space is required for the storage of natural gas as compared with the diesel fuel storage requirements. This translates to about 40 cubic feet of storage space for the fuel, which can be accommodated by 20 - 9 inch diameter by 56 inch long commercial gas cylinders. In addition, because of the higher pressure of the storage cylinders, there is a substantial additional weight to be carried; 20 cylinders would weigh approximately 1360 kg (3,000 lbs). Even at this, the bus would not have the range of a conventional bus which is approximately 500 km to 800 km or 300 miles to 500 miles under urban traffic condition.

The significant benefit attributable to natural gas is its substantial surplus supply at the present time. Also on a per unit of energy basis it is cheaper than diesel fuel, gasoline or propane at the present time. Including costs of supply and compression, natural gas should cost approximately 15-20% less than propane on an energy equivalent basis.

The volume of on-board storage required and the total weight of the cylinders can be reduced by the use of liquefied natural gas, but the cost of

the liquefaction plant and the storage cylinders (which are insulated to maintain the liquid fuel at - 167°C) would result in a fuel cost considerably higher than other available alternatives, such as propane.

## SUPPLY AND PRICE OF ALCOHOL FUELS

Over the past decade substantial progress has been made in the development of internal combustion engines to run on alcohol fuels. One of the leaders in this respect is Brazil where 100% alcohol fuelled vehicles are now in production and service stations dispensing fuels made largely from sugar cane and wood waste are being opened.

There are at least three types of alcohols which are suitable for use as an automotive fuel, methanol, ethanol and butanol. These fuels can be readily produced today from a wide range of feedstocks including coal, biomass and other types of resources, found in most regions of Canada. The raw materials and costs of production are different for the many different processes available.

There is a continuing interest in the development of the processes used to produce alcohol. The Alberta Government has recently let contracts to design a demonstration plant to produce alcohol from biomass. A smaller scale commercial plant operation just opened in Manitoba by Mohawk Oil Company Ltd. to produce alcohol from grain is one example of developments in the alcohol fuels area.

The principal difficulty with alcohol fuels is that they cannot be substituted for hydrocarbon fuels used today without major engine modifications. Alcohol/gasoline blends (10% alcohol, 90% gasoline) are in relatively common use in the United States and have just become available in Manitoba. Gasohol requires anhydrous alcohol to be mixed with gasoline or the water in the alcohol will separate in the fuel tank. As the heat energy in ethanol and methanol is approximately 50 - 70% per liquid gallon of that for gasoline, more must be carried to give equivalent range as fuel economy per liquid measure. Poor cold starting characteristics due to the high latent heat of vapourization of alcohol may also present problems.

Alcohol has certain advantages as an automotive fuel. It provides high octane values and, because of improved combustion efficiency when compared to diesel fuel, it produces lower emissions of substances now regulated.

In summary, a good deal more development work needs to be undertaken to bring down the price of alcohol fuels from biomass or other sources before they will be competitive with gasoline and diesel fuel. Once such development work has proven successful, then alcohol could be a major source of liquid fuels for transportation use in Canada. Certainly the supply of raw materials is available in abundance. As shown in Appendix E, our projection of the price of ethanol produced from municipal waste is that it might cost as low as 30¢ per litre equivalent of gasoline in 1981 dollars, based upon a 1985 start-up date.

## SUPPLY AND PRICE OF ELECTRICITY

One very real alternative to diesel fuel on the Winnipeg Transit fleet is to convert some or all of the fleet to electric propulsion. This may be by the use of vehicles that pick up electrical power from overhead sources or by battery power. Both require a source of available and inexpensive electrical energy.

Exhibit 2.3 shows the historical price of electrical energy in Manitoba. This exhibit shows that the price of electrical energy in Manitoba has remained quite stable, and in real terms has declined since 1967.

Information provided to us by Manitoba Hydro indicates that in 1980 to 1990 period they anticipate an approximate 50% increase in the demand for electric power, and in the period from 1990 to 2000 they anticipate a further 50% increase, so that at the end of the two decades the power consumption will be twice the 1980 level. They have programmed additional generation facilities to accommodate this demand forecast.

Financial studies undertaken by Manitoba Hydro have indicated that the price of electric power will increase by about 40% in current dollars over

**exhibit 2.3**

## Cost of Electric Power in Manitoba

(Cents per kWh)

| YEAR END | STANDARD RESIDENTIAL | COMMERCIAL | INDUSTRIAL |
|---|---|---|---|
| 1967 | 1.14 | 2.02 | 0.68 |
| 1970 | 1.19 | 2.03 | 0.68 |
| 1975 | 1.58 | 2.64 | 1.02 |
| 1980 | 3.09 | 4.13 | 1.94 |
| 1981 | 3.09 | 4.13 | 1.94 |
| 1990 Forecast | 4.33* (6.67)+ | 5.79* (8.86)+ | 2.72* (4.19)+ |
| 2000 Forecast | 7.42 (14.40) | 9.91* (19.25)+ | 4.66* (9.04)+ |

NOTES: * Forecast by Manitoba Hydro.

+ Extrapolation of 1981 prices based on same inflation rate as cost forecast.

the period to 1990, and by a further 100% per the period from 1990 to the year 2000. These projections have assumed 8% inflation rate for capital costs and operating costs. The resulting 1990 and 2000 costs of electric power in Manitoba according to these forecasts are shown on Exhibit 2.3. Also shown in brackets is the cost at these points in time if the rates per kilowatt hour inflated from 1980 at 8% per year, consistent with the assumptions regarding capital and operating cost increases. It can be seen that this results in higher prices in current dollars. In other words the Manitoba Hydro forecasts imply that the real cost of electricity will decline over the next 20 years.

It appears appropriate for the purpose of this study to assume that the electric power rates in Manitoba at a minimum will increase with inflation, if for no other reason than competing power and fuel costs will likely increase much more rapidly than this. Therefore in this study, the price of electricity was assumed to remain at 1981 levels in constant dollars.

## 3. ANALYSIS OF FUTURE TRANSPORTATION REQUIREMENTS

Transit demand characteristics are important in assessing the feasibility of alternative transit service power sources because of their impact on transit routing and service frequencies. The purpose of this chapter is to provide background on expected and possible transit demand characteristics in Winnipeg to provide a context in which to assess alternative energy sources. Accordingly, this chapter deals with:

- o present, past and future ridership and service characteristics of Winnipeg Transit. For comparison purposes, information has been gathered and summarized on transit service characteristics of four other Canadian cities of a similar size;
- o peak hour ridership forecasts on the major future transit corridors. These volumes and the associated service requirements have an important bearing on the feasibility of establishing infrastructure-related alternative power sources;
- o the potential impact on ridership of significant increases in gasoline prices;
- o the likely impacts of severe gasoline shortages.

### RIDERSHIP AND SERVICE CHARACTERISTICS

Winnipeg Transit serves a population of approximately 570,000 people, generating over 60 million revenue passengers per year with approximately 25.6 million vehicle-kilometres of service per year. The 105 rides per capita and 2.32 revenue passengers per vehicle-kilometre operated are within the range of expected values for an urban area of this size.

Winnipeg Transit maintains a fleet of approximately 535 active vehicles of which 477 are required for p.m. peak service and 454 units are required for typical winter a.m. peak service. The majority of the 61 routes (including express services) focus on the downtown which in 1976 was the destination for 48% of all a.m. peak hour passenger work trips.

The current a.m. peak transit mode share of work trips is approximately 22% for the entire study area and 41% for trips destined to the downtown. On a typical week day Winnipeg Transit carries approximately 200,000 revenue passengers of which approximately 21,000 are a.m. peak hour trips.

Exhibit 3.1 illustrates the breakdown of weekday ridership by age group and time of day. Approximately 72% of the revenue passengers are adults with students and senior citizens accounting for 17% and 11%, respectively. Exhibit 3.1 also indicates the tendency of senior citizens, and to a lesser extent students, to use the transit service during off-peak periods (approximately 75% of senior citizens' transit trips are made between 8:30 a.m. and 3:30 p.m.).

**Recent Trends**

In 1970 Winnipeg Transit carried approximately 58.7 million passengers and in 1980, 60.4 million passengers for an overall growth rate of 0.6% per year. However, annual ridership peaked in 1975 with 66.7 million passengers and since 1975 ridership has decreased by approximately 10%.

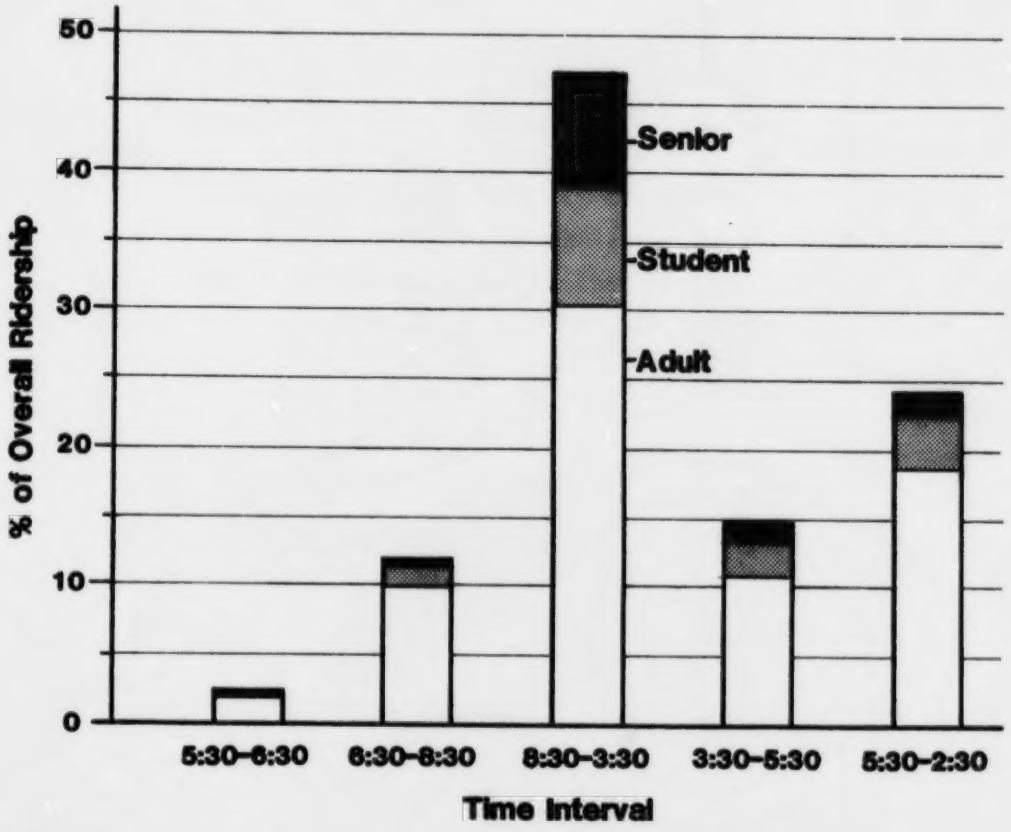
Although total ridership is important, other measures of effectiveness (e.g. passengers per kilometre, kilometres per capita, etc.) are important indicators in identifying trends. Exhibit 3.2 summarizes historical information for Winnipeg Transit and for four other cities in Canada of comparable size, Edmonton, Hamilton, Calgary and Ottawa. With respect to Winnipeg Transit, Exhibit 3.2 indicates that:

- the ratio of revenue passengers per vehicle-kilometre of service is decreasing. In 1974, Winnipeg Transit had approximately 2.6 revenue passengers per kilometre while in 1980 there were 2.32 revenue passengers per kilometre. This represents a net reduction of approximately 10%;

- over the same time period, the annual vehicle-kilometres of service per capita increased from approximately 41 kilometres to approximately 45 kilometres per capita in 1980, an increase of approximately 10%;

**exhibit 3.1**

**Ridership Volumes for an Average Weekday**

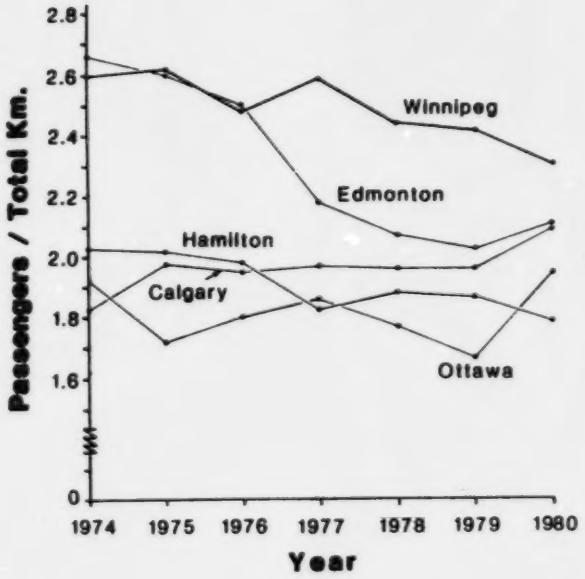



**Source: Transit Fare Survey (1980)**
**Winnipeg Transit**

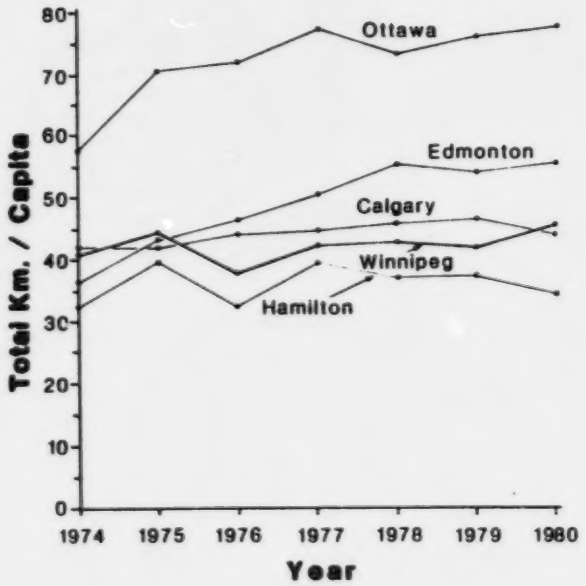
**exhibit 3.2**

## Historical Comparison of Transit Service Characteristics

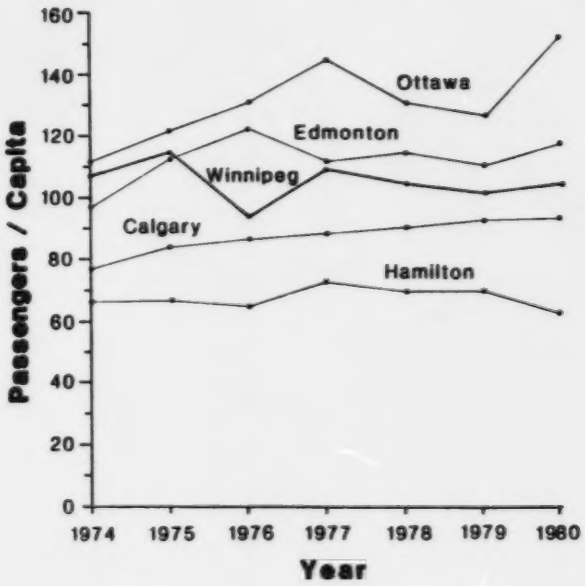
**Passengers / Total Km.**
**for Winnipeg and Comparable Cities**




**Total Km. / Capita**
**for Winnipeg and Comparable Cities**




**Passengers / Capita**
**for Winnipeg and Comparable Cities**




Source: Canadian Urban Transit Association, Survey Statistics

- between 1974 and 1980, the annual passengers per capita remained virtually unchanged.

The historical characteristics of Winnipeg Transit would thus suggest that, although transit service is being expanded, it is being increased into areas that are difficult to service (e.g. long trip lengths, low density development, etc.) or during time periods where transit ridership is low and not sensitive to improved frequencies.

As is evident from Exhibit 3.2, many of the other cities examined reflect the same trends as Winnipeg in that passengers per kilometre are decreasing or staying constant, total kilometres per capita are increasing, and passengers per capita are not changing appreciably. Although there are a number of reasons why this has occurred, one of the more obvious ones is that population growth in these urban areas occurs generally in the suburbs which are further from the primary destinations which are usually in the downtown; the suburban areas have a lower population density and are more difficult to serve, and many of those who commute from suburban areas have a more diverse range of trip destinations which are also more difficult to serve by transit. Another factor that has some effect on transit service efficiency is the destination of work trips. In many urban areas, major employment centres are being established in the fringe areas outside of the downtown.

The effect of these development patterns on transit is illustrated by Winnipeg where between 1962 and 1976, a.m. peak hour work trip ridership increased by a total of 6% (0.4% per year). During the same period, the proportion of total a.m. peak hour transit trips destined to the downtown decreased from 67% in 1962 to 48% in 1976. By contrast, transit work trips destined to the outer areas of the city increased from 5% of the total transit work trip demand in 1962 to 20% in 1976. These changes in ridership patterns can be explained, in part, by:

- the dispersed nature of population growth: between 1962 and 1976 population in the outer areas of Winnipeg grew by 170% whereas population in the inner areas of the city decreased by approximately 30,000 people;

- dispersed employment growth: whereas the total employment for Winnipeg increased by 72,000 between 1962 and 1976, employment in the downtown which is the primary transit market decreased by 6,000 employees.

There have been a number of demographic and socio-economic characteristics that have also had an adverse impact on transit ridership. Between 1962 and 1976, the average number of persons per dwelling unit in Winnipeg decreased from 3.73 persons per household to 2.95. This combined with the increase in the employment participation rate from .318 in 1962 to .396 in 1976 suggests that a prime transit market (children, students, housewives), especially for off-peak trips, has been reduced relative to the total population. Moreover, the increased employment participation rate would suggest that household incomes are increasing in real dollars. Typically, as household income increases, auto ownership increases and transit utilization decreases. This seems to be the case in Winnipeg where in 1962 there were approximately 125,000 vehicle registrations and in 1976 there were approximately 225,000 vehicle registrations. The number of persons per registered passenger vehicle which has decreased from approximately 3.8 in 1962 to 2.6 in 1976.

These factors and the patterns of population and employment growth, explain a large part of the trends in Exhibit 3.2 as well as the fact that in Winnipeg the transit share of total a.m. peak hour work trip travel has decreased from 28.1% in 1962 to 21.9% in 1976. For the same period the transit work trip modal split to the downtown decreased from 48% to 41%.

The recently completed Winnipeg Development Plan addresses, in part, the problems of dispersed population and employment growth.

**Forecasts**

The forecasted 1999 population for Winnipeg is 668,000 (an annual growth rate of 0.7%) and the forecasted 1999 employment is 277,000 (an average annual growth rate of almost 1%). The recommended land use plan would accommodate most of this growth through infilling rather than by the continuation of decentralized growth.

Based on the Plan Winnipeg Transportation Component forecast, the a.m. peak hour transit ridership is expected to increase from 19,500 in 1976 to 28,300 in 1999, an annual growth rate of 1.6%. The higher growth rate in transit ridership compared with the growth for population and employment implies that transit will acquire a larger share of the travel market. The modal split forecasts are as follows:

| | Current | 1999 |
|---|---|---|
| Transit Modal Share (Total Work) | 22.8% | 26.7% |
| Transit Modal Share (Downtown) | 41.3% | 52.1% |

A major reason for the larger share is the expected growth in transit demand to the downtown; the 1999 forecasts indicate that the downtown will account for 53% of all a.m. peak hour transit trips compared to the existing level of 48%. The two other major transit destinations are the St. James industrial area and the University of Manitoba which account for 14.0% and 12.5% of the 1999 forecasted transit trips respectively.

The expected composition of the 1999 population indicates that off-peak ridership will grow slightly more than peak ridership. Exhibit 3.3 summarizes estimates of 1980 and 1999 ridership by age group and time of day. The estimates, which were based on a 1980 revenue passenger survey and 1980 and 1999 population distributions by age, suggest that the relationship between a.m. peak and mid-day ridership will change marginally. Assuming that there will not be a change in frequency of travel for each of the age groups, the estimated differential growth in off-peak ridership would range from 5% to 15%; that is, if the peak ridership increases by 45% as forecasted, the off-peak ridership might grow by 47.3% to 51.8%. Based on an examination of mid-day load factors at a few selected maximum load locations, this differential growth should not require additional off-peak transit service. In subsequent chapters of this report we have assumed that the ratio of peak to off-peak service would remain similar to that provided today.

**exhibit 3.3**

**Comparison of Average Weekday**

| TIME INTERVAL | STUDENT | | ADULT | | SENIOR | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | 1980 | 1999 | 1980 | 1999 | 1980 | 1999 | 1980 | 1999 |
| 5:30 a.m. to 6:30 a.m. | 0.0% | 0.01% | 2.3% | 2.34% | 0.1% | 0.08% | 2.4% | 2.4% |
| 6:30 a.m. to 8:30 a.m. | 1.8% | 1.35% | 10.0% | 10.11% | 0.2% | 0.28% | 12.0% | 11.8% |
| 8:30 a.m to 3:30 p.m. | 8.4% | 6.45% | 30.5% | 31.0% | 8.3% | 10.4% | 47.2% | 47.9% |
| 3:30 p.m. to 5:30 p.m. | 2.5% | 1.90% | 10.9% | 11.0% | 1.2% | 1.5% | 14.6% | 14.4% |
| 5:30 p.m. to 2:30 a.m. | 4.2% | 3.27% | 18.3% | 18.5% | 1.3% | 1.6% | 23.8% | 23.4% |
| TOTAL | 16.8% | 13.0% | 72.0% | 73.1% | 11.1% | 13.9% | 100% | 100% |

* Based on participation rates calculated from 1980 passenger survey, and City of Winnipeg forecasted population age distributions.

At present, Winnipeg Transit consumes approximately 15.5 million litres of diesel fuel per year. Assuming that total system kilometres of service would increase in proportion to the forecasted increase in a.m. service and that the consumption rate remains constant per vehicle-kilometre, fuel requirements would increase by over 70% by 1999. Because of transit priority facilities included in the plan, average operating speeds are projected to increase from 16.0 km/h to 18.5 km/h, an increase of approximately 16%. This increased speed could result in a 10% improvement in fuel efficiency. Assuming that only 50% of off-peak service would benefit from the improved operating speeds, the overall improvement in fuel efficiency would be approximately 6% with a resulting 1999 demand for 25.0 million litres; a 61% increase in total fuel consumption relative to 1980.

## TRANSIT CORRIDORS

Because of the radial nature of the street system in Winnipeg, travel demand trends to be consolidated among major radial corridors. The transportation component of the Winnipeg Development Plan includes priority measures for public transit along the major corridors leading to the downtown consisting of:

- an exclusive bus lane on Portage Avenue between the downtown and the Grace General Hospital;
- a busway on the CN Rail right-of-way between the downtown and the University of Manitoba (southwest corridor);
- a busway adjacent to the CN Rail right-of-way east from the downtown to Regent Avenue. Another busway would lead from the CNR right-of-way southeast to Southdale;
- an exclusive bus lane on Main Street between the downtown and Partridge Avenue;
- a combination exclusive bus lane and busway from the downtown northwest to Inkster Boulevard.

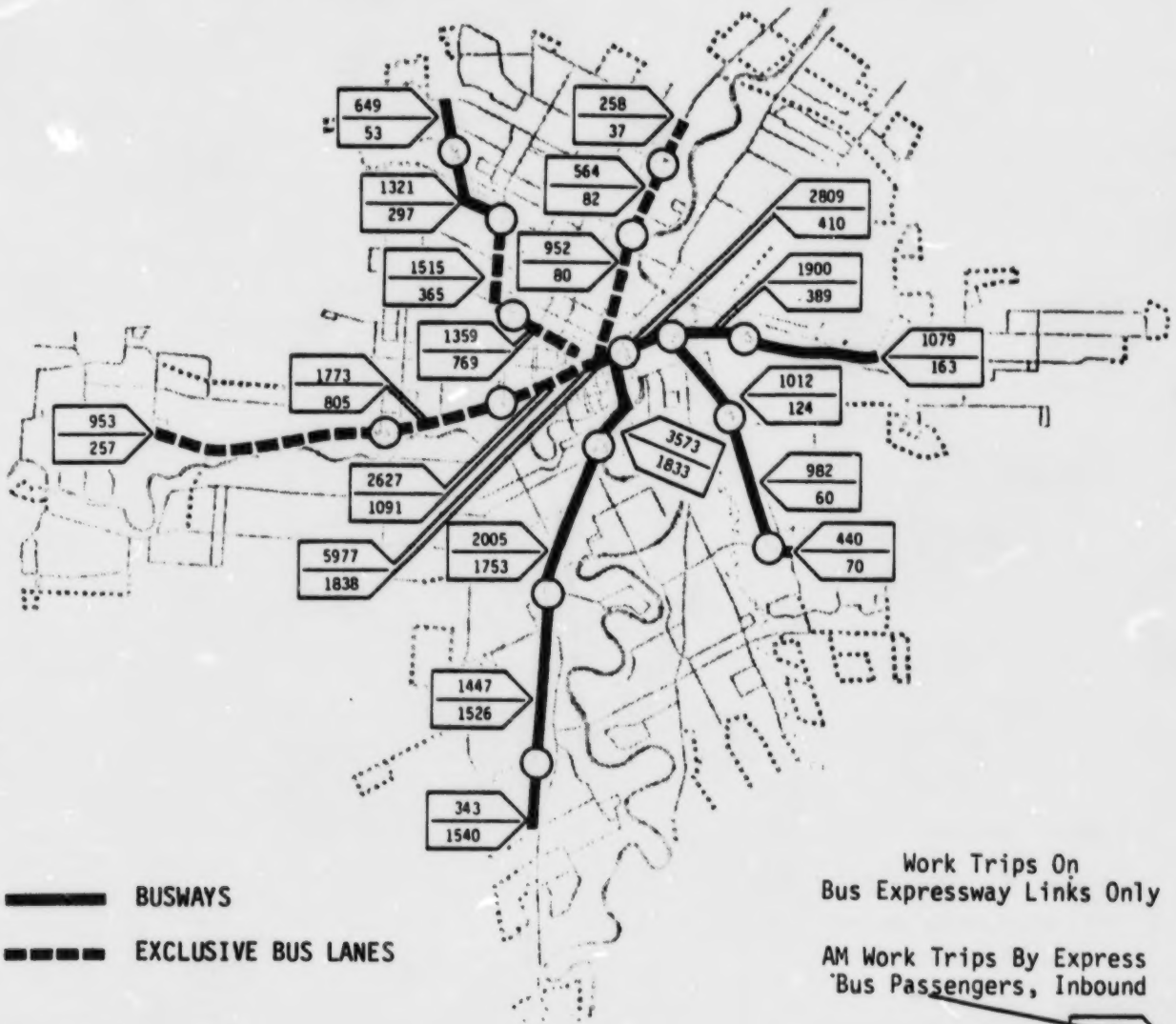
Exhibit 3.4 illustrates the forecasted 1999 a.m. work trips assigned to these facilities. The projected one-way passenger volumes on these facilities range from 1,000 to 3,600 a.m. peak hour work trips. The highest demand is on the southwest busway adjacent to the Pembina Highway which has 3,600 a.m. peak hour inbound work trips at the maximum load point. This facility is unique in that there is also a heavy outbound demand destined to the University. The second major facility is the exclusive bus lane on Portage Avenue which has 2,600 a.m. peak work trip passengers at the maximum load point into the downtown. Other corridors of the city have, in some cases, similar demand forecasts but these high loads are over shorter distances. Because of the long trip lengths, high volumes and the high priority given to these preferential transit facilities in the Transportation Plan, they are discussed in more detail below.

Exhibit 3.5 summarizes 1980 and 1999 screenline transit demand along the two major corridors; the Pembina Highway corridor and Portage Avenue. It is important to note that Exhibit 3.5 includes total a.m. peak hour trips and not just work trips. Also, the values shown reflect ridership on the several routes which pass the screenline. The passenger growth rate along the corridors are significant: 5% per annum on the Pembina corridor and 3% in the Portage corridor. These are greater than Winnipeg Transit's average projected growth rate of 1.6% per year and thus, the two corridors are anticipated to capture an increasing share of the transit ridership owing to higher level of transt ridership and relatively high residential growth in the Pembina corridor.

Exhibit 3.6 illustrates the transit demand characteristics along the Pembina Avenue corridor as estimated for 1999 by the EMME model. The busway maintains high two-way volumes throughout its length with the most concentrated demands occuring after Osborne Street going into the downtown where the peak hour work trip volume is in excess of 3,500 passengers. The outbound volume along the busway is typically in the range of 1,500 to 1,800 passengers. A high percentage of the growth in demand to the downtown along this corridor is a result of passengers from the residential areas to the west using feeder services to this corridor.

**exhibit 3.4**

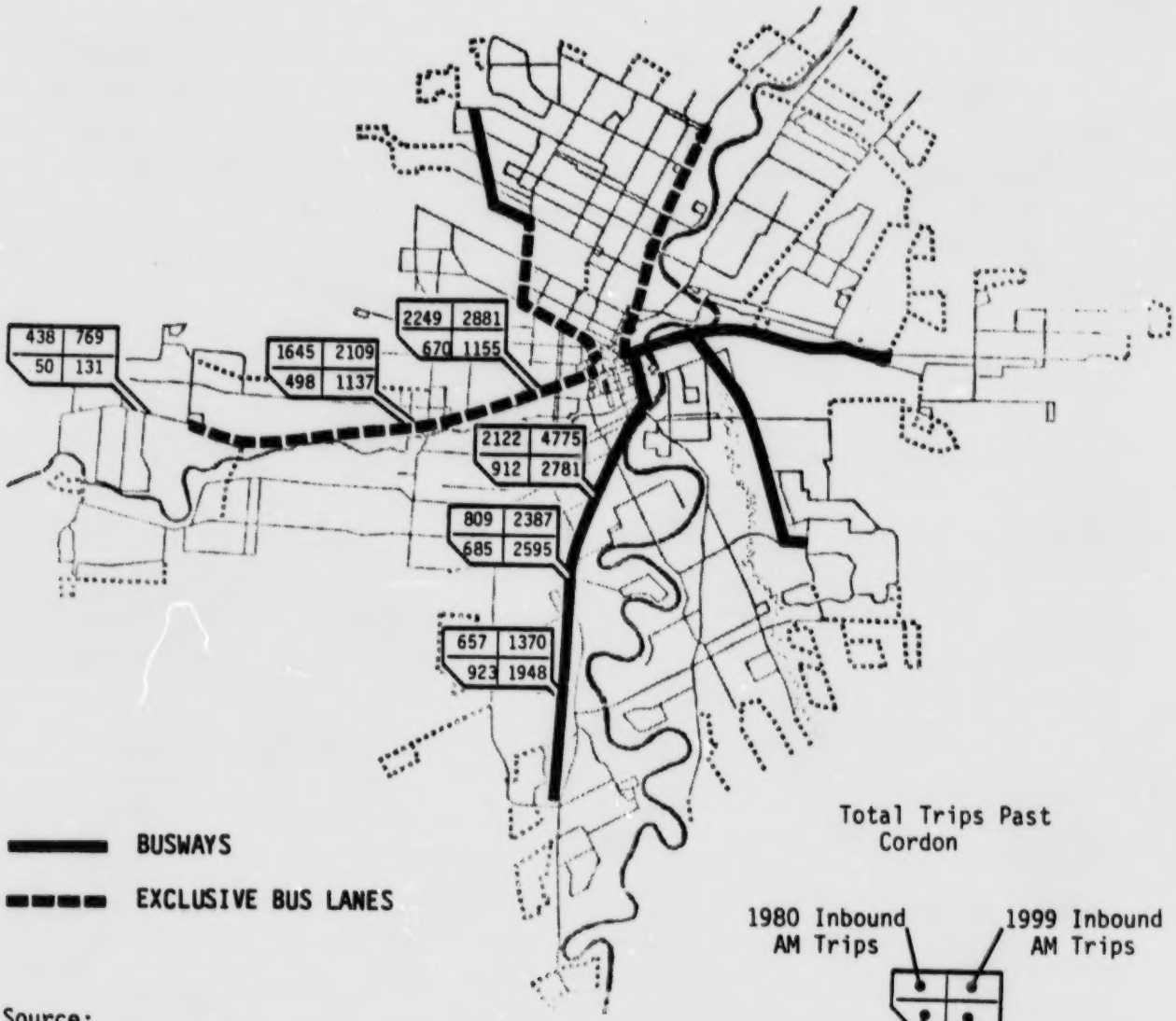
**Passenger Volumes on Bus Expressways in 1999 as Predicted by EMME**




**Source:**
**Travel Forecasts by EMME Model for the City of Winnipeg, 1999 Preferred Land Use Plan / Transit Priority System**

**exhibit 3.5**

**Comparison of Maximum Load Points on Pembina and Portage Corridors Current 1980 vs. Forecast 1999**




Source:

Survey Passenger Counts Conducted on Pembina and Portage Corridors from September, 1980 through February, 1981 and EMME Link Volume Forecasts

**exhibit 3.6**

**Link Volumes in the Southwest Corridor - A.M. Peak Period**

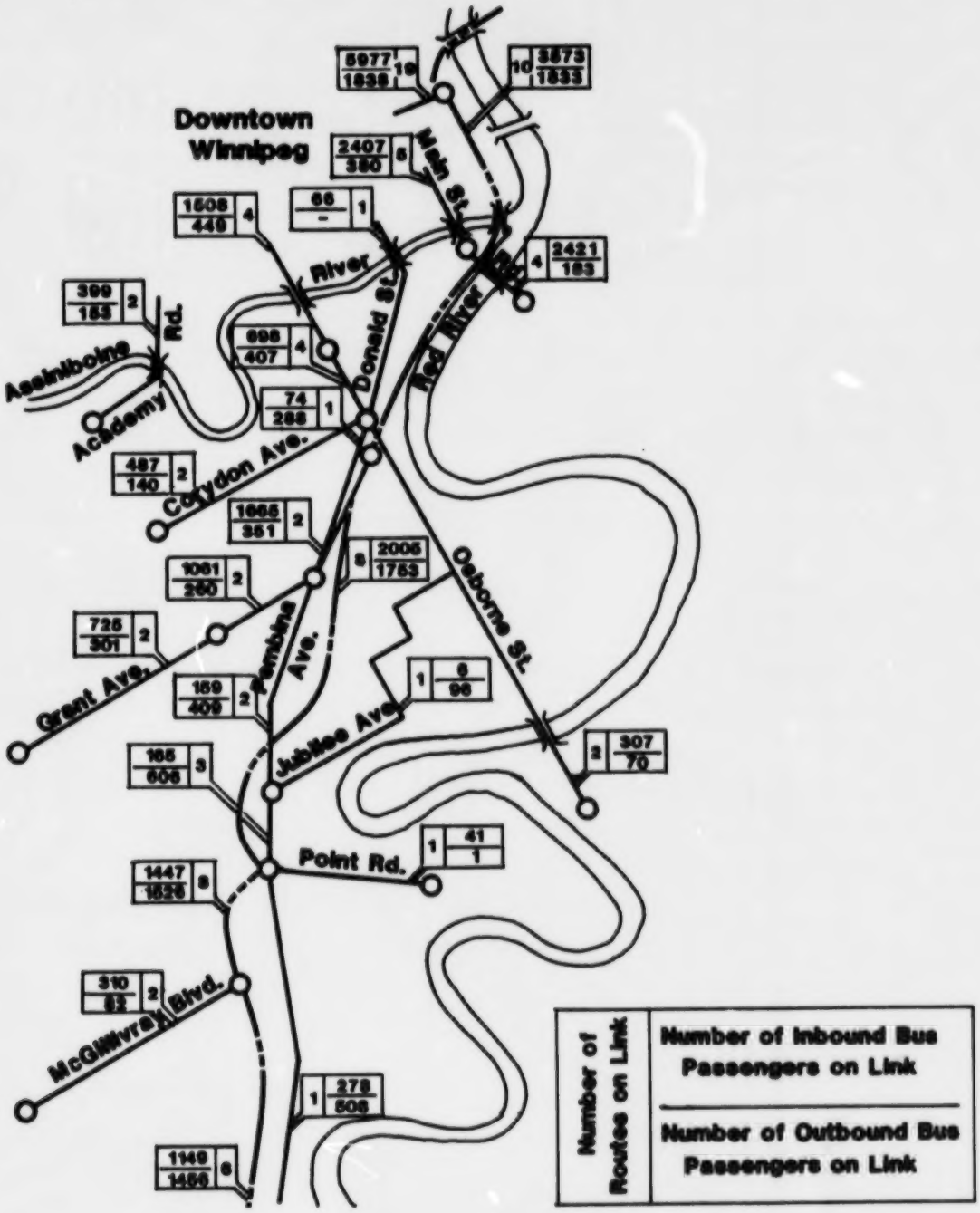


**exhibit 3.7**

**Link Volumes in the Portage Corridor–A.M. Peak Period**

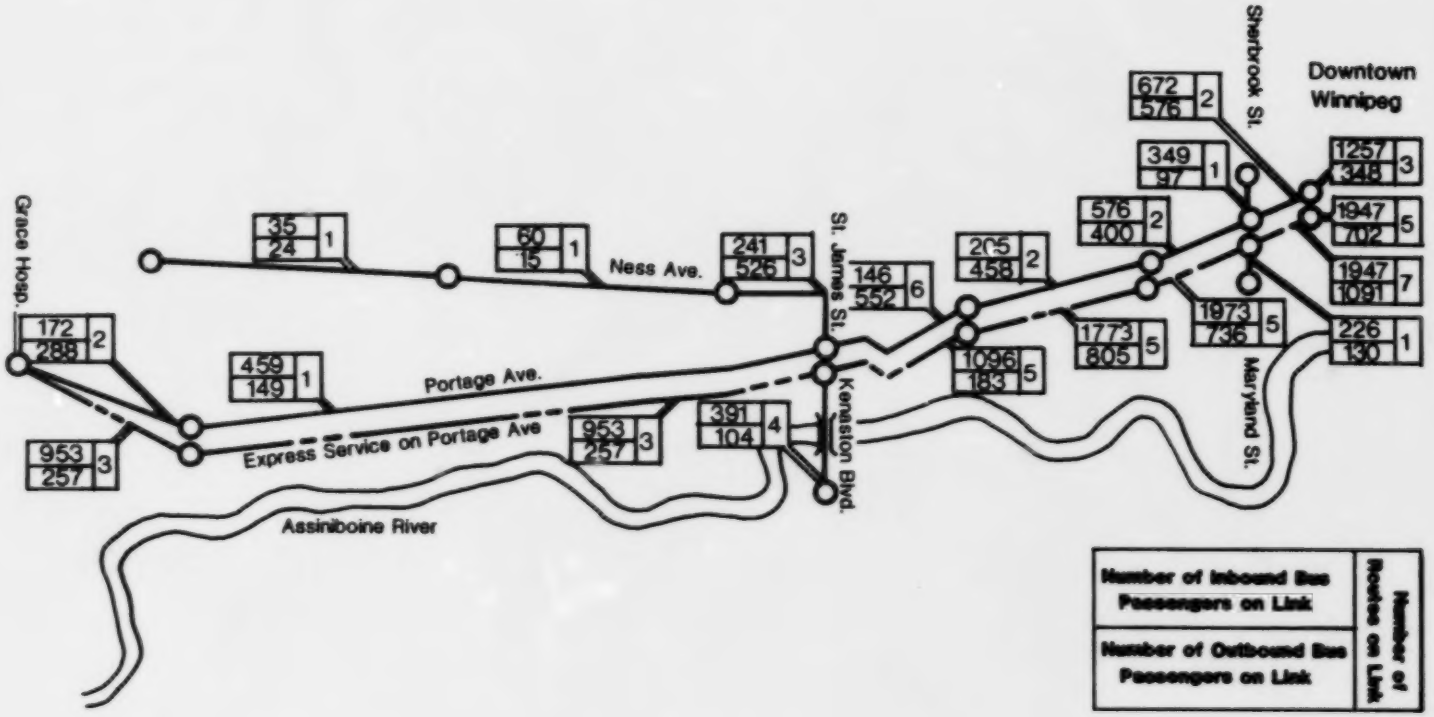


Exhibit 3.7 summarizes the a.m. peak hour work demand for the Portage Avenue busway including the exclusive lane. The inbound demand ranges from approximately 1,000 passengers up to approximately 2,500 passengers. Between the downtown and Kenaston Boulevard, there is a significant outbound movement of approximately 1,000 passengers. West of Kenaston Boulevard, the demand becomes much more directional with the major flow being inbound to the downtown.

Factoring the ridership forecasts in Exhibits 3.6 and 3.7 at the maximum locations to reflect total a.m. peak hour ridership results in a peak load on the Pembina corridor busway of 3,800 passengers and 2,200 on the Portage Avenue exclusive bus lane. These demand levels could easily be accommodated on the respective facilities; the capacity of exclusive bus lanes is 8,000 passengers per hour and busways can accommodate up to 15,000 passengers per hour.

## IMPACTS OF ENERGY PRICING

There are a number of factors which could affect the ridership forecasts, one of which is gasoline pricing. There is little experience regarding the effect of gasoline pricing on private auto use and transit ridership because until 1978/79 the real price of gasoline had decreased relative to the 1950 price. However, there have been significant real price increases of gasoline since 1978/79 and, because gasoline is derived from a limited natural resource, it would be reasonable to expect that real prices would continue to rise. As discussed in the previous chapter the National Energy Program and the Federal/Provincial energy pricing agreements project such increases.

In estimating the ridership implications of real price increases three techniques were applied:

1. The EMME modal mode split equation. In the Plan Winnipeg study a modal split was calibrated. This EMME model does not take into account auto operating costs but does include parking costs. It was assumed that any real increases

in auto operating costs would have a similar effect to an increase in parking costs. As a means of reflecting modal effects of fuel pricing, fuel costs were identified on an O/D interchange basis and the new modal splits calculated.

2. Documented elasticities between increased auto operating costs and transit ridership, reflecting experience in the U.S.

3. The actual experience of transit properties during periods of escalating gasoline costs.

The results from the use of the EMME modal split model indicate that with a 100% increase in the real price of fuel, there would be a 22.5% increase in transit usage for CBD destined work trips and a 37.9% increase for non-CBD work trips. Because the 1999 forecasts suggest that 53% of the peak hour work trips are destined for the downtown, the EMME model results would indicate an average increase in transit ridership for work trips of about 30%.

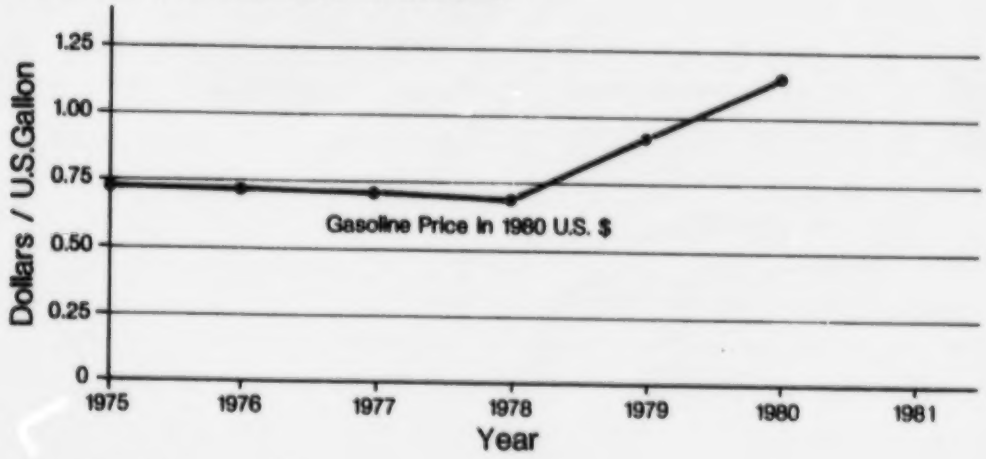
The second method of estimating the effect of fuel price increases is based on the documented elasticities of travel demand with respect to fuel price. Published sources suggest that a 100% increase in fuel prices would increase CBD trips by 16% and non-CBD trips by 19.5% for an overall increase of approximately 18%. These elasticities are based on U.S. experience as documented in "Patronage Impacts of Changes in Transit Fares and Services" (Urban Mass Transportation Administration, Contract No. DOT-UT-90014, September, 1980).

The third method employed in comparing gasoline costs and transit ridership impacts was based on actual ridership figures and gasoline costs. Exhibit 3.8 summarizes the real gasoline costs in the U.S. for the period 1975 through 1980. As shown in the exhibit, the price per gallon did not change appreciably between 1975 and 1978. However, in 1979 the real price increased by 38% as compared to 1978 and 23% in 1980 as compared to 1979. As illustrated by the transit ridership shown, some properties did not have an appreciable change in ridership whereas some properties such as Louisville increased by 15%. A study which is currently underway in New York City is analyzing the elasticities between fare, ridership, and gasoline prices and

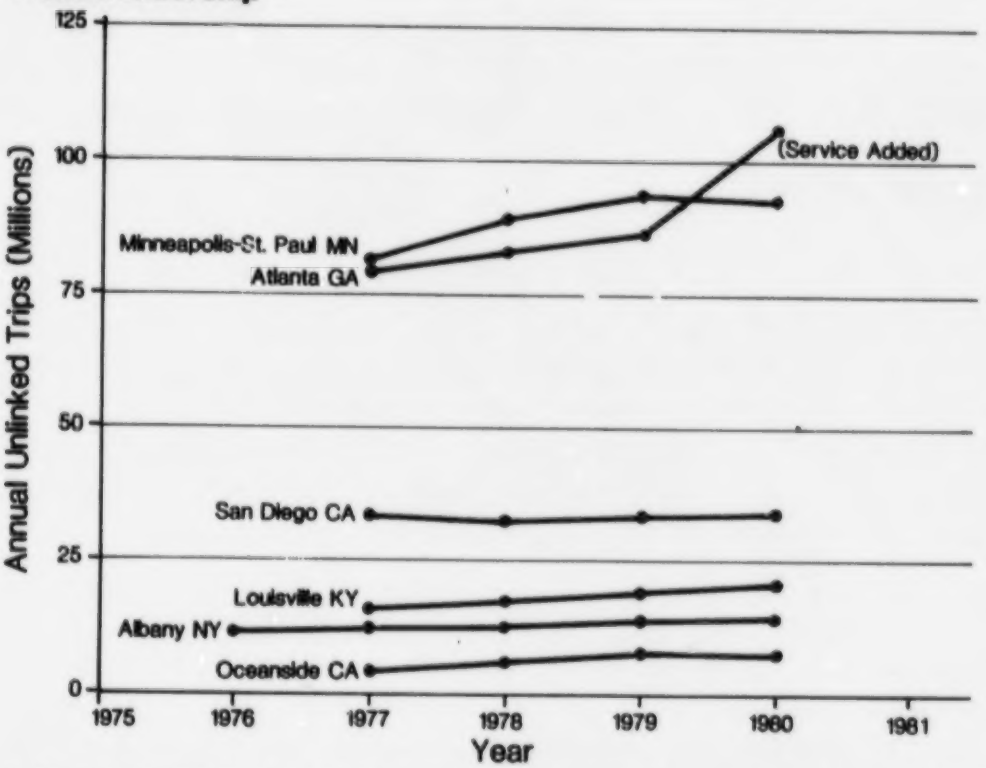
**exhibit 3.8**

**Comparison of Ridership Trends and Real Gasoline Costs**

**Real Cost of Gasoline in the U.S. ***




**Transit Ridership ○**




* Source: Scientific American, Fuel Economy of Light Vehicles, Vol. 244, No, 5, May 1981, p. 52

○ Source: APTA Ridership Survey Statistics

has to date estimated that the elasticity between transit ridership and gasoline prices is 0.30. This elasticity with an assumed 100% increase in fuel prices would result in a 22% increase in ridership.

Based on the foregoing analysis, it would be reasonable to conclude that a 100% increase in real gasoline prices could result in a 20% increase in ridership. This is probably high in terms of revenue passengers because as real fuel prices increase substitutions occurs; people buy more fuel-efficient vehicles, enter carpools or make fewer trips.

From the analysis it is reasonable to conclude that, as real fuel prices increase, there is a disproportionate increase in non-CBD transit trips. It may, over the long term, have some effect on transit routing, with more cross-town services, especially to major employment centres. However, the major concentration of trips would still be to the CBD and the use of proposed bus lanes and busways would be of major importance. Moreover, such facilities could be used effectively to accommodate cross-town demand assuming that buses could be interlined and transfer delays kept to a minimum. One of the advantages of increased cross-town demand is that it could be accommodated because of available capacity in the off-peak direction.

## GASOLINE SHORTAGES

The U.S. gasoline shortages in 1979 did have some effect on transit ridership although, as shown on Exhibit 3.8, it is difficult to isolate this effect from the effects of increases in the real price of gasoline. However, a theoretical estimate was developed for Winnipeg Transit of a 15% shortfall in petroleum supplied (the reasons for choosing 15% are described in Chapter 2) to at least provide a framework and basis for comparison with experience elsewhere.

In the short-fall analysis, it was assumed that a 15% shortage in petroleum supplies would result in a 20% reduction in gasoline availability for private automobiles. It was assumed that work trips would be less adversely affected than non-work trips because the latter are in many cases

discretionary and that the reduction in automobile work trips would be 15%. These trips were then assigned to other commuting modes including auto passenger, to reflect increased carpooling, and public transit. This procedure resulted in a 5% increase in the auto occupancy rate (1.20 to 1.26) and a 28% increase in transit work trips. This result is most likely high because it does not take into full account the captive nature of many auto users nor the importance of rider-sharing (carpooling and vanpooling) during energy shortages. With regard to the latter, ride-sharing offices have been shown to increase auto occupancy rates for applicants from 1.2 to over 2.5. As for off-peak transit trips, it would be reasonable to expect a similar increase in these trips because it would be a substitute mode for what would be more probably discretionary auto trips.

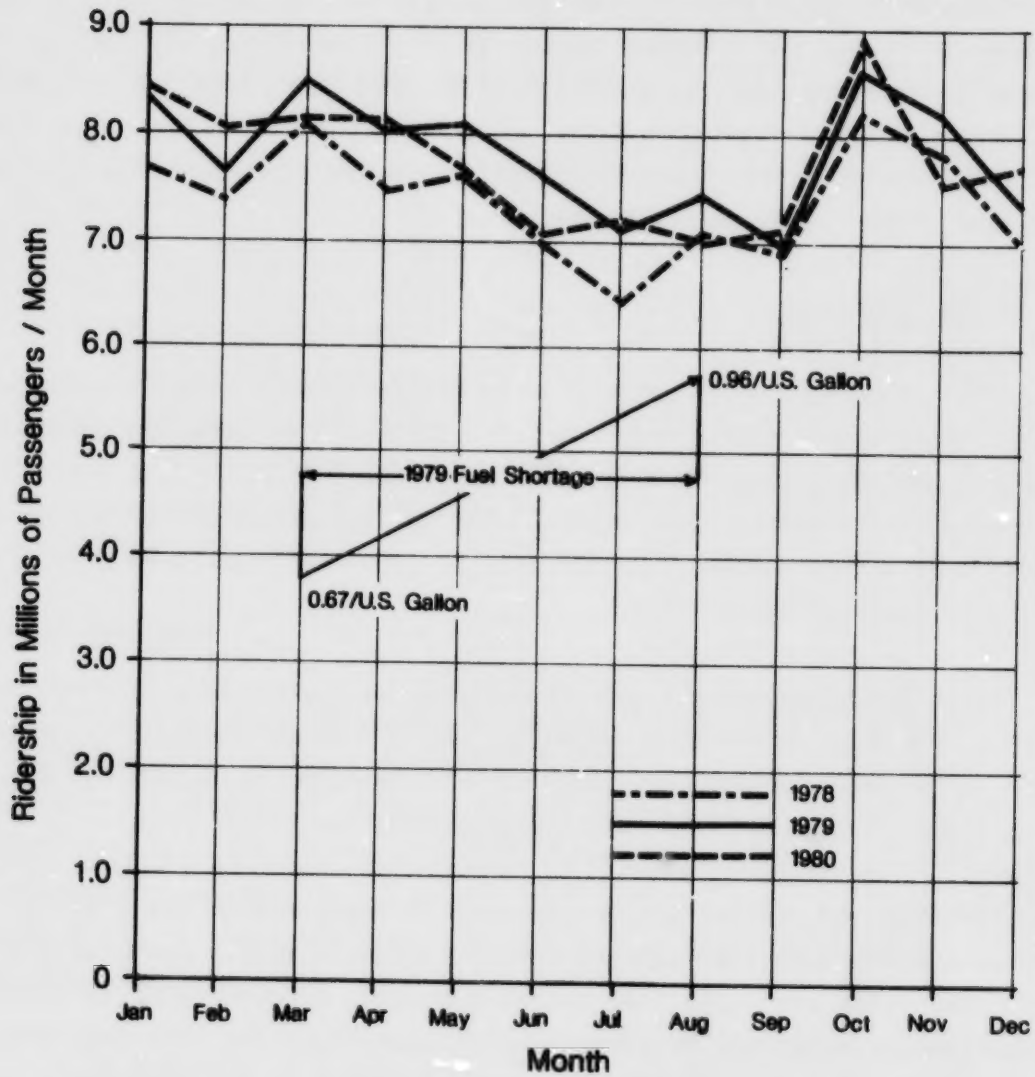
## U.S. Experience

Information was gathered on the actual transit impact in Minneapolis - St. Paul of the 1979 energy shortage. Exhibit 3.9 summarizes the month by month ridership between January, 1978 and December, 1980. From the exhibit, ridership increased by approximately 6.5% over the period of the energy shortage. During this period, fuel prices also increased significantly from 67¢ a gallon to 96¢ per gallon (U.S.).

Exhibit 3.10 is a plot of the gasoline distribution by month for the State of Minnesota for 1978 and 1979. As is evident from the Exhibit, the average decrease in available gasoline in 1979 relative to 1978 was 8.5%. It is, however, estimated that this was a real 10% short-fall as measured against demand. The resulting elasticity of transit demand to gasoline supply is -0.75 for a decrease in fuel supply which is considerably less than the theoretical estimate of fuel supply elasticity based on travel characteristics for Winnipeg which was -1.5. The probable reasons for this are, as previously discussed, a reduction in discretionary auto trips, the fact that many auto work trips are captive, and increased rider-sharing (e.g. carpooling).

**exhibit 3.9**

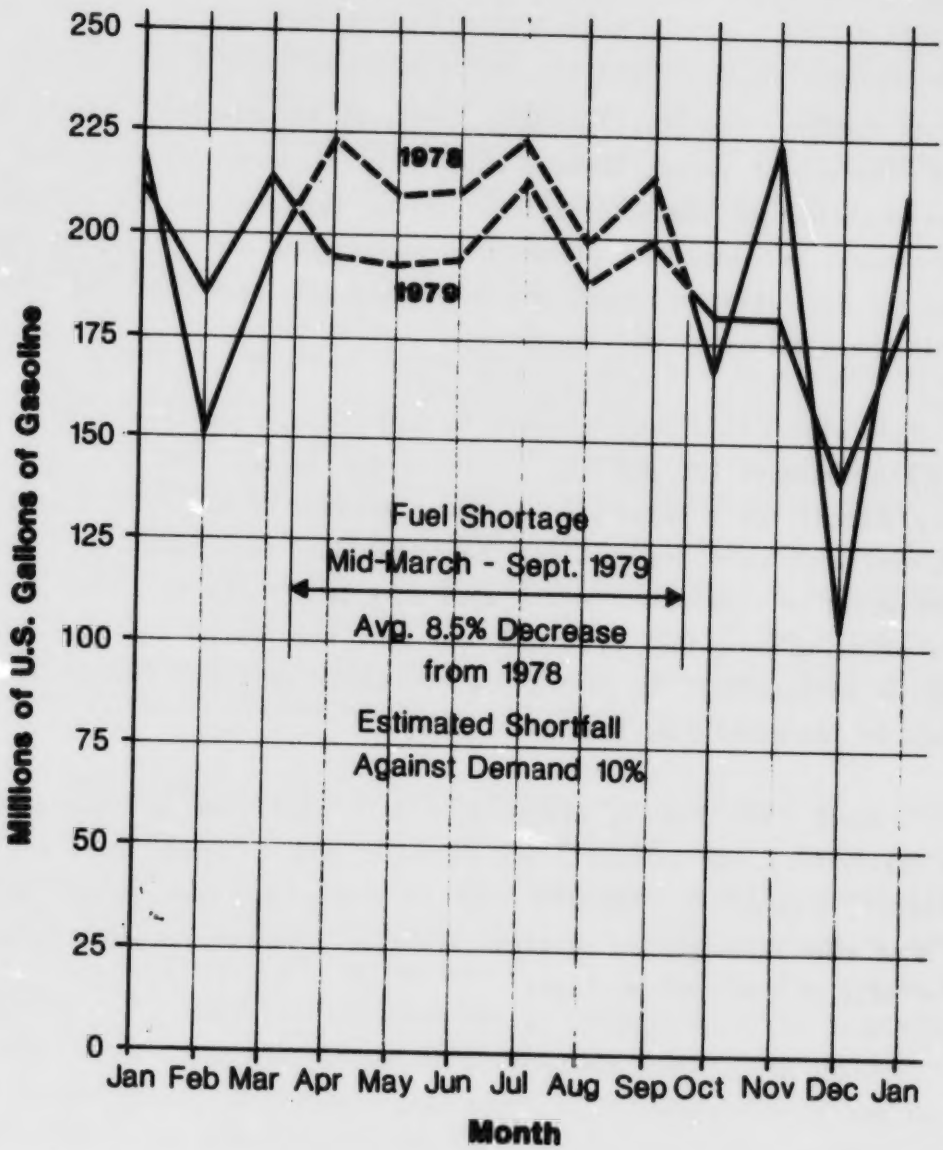
**Minneapolis-St.Paul Monthly Ridership Changes Arising from the 1979 Fuel Shortage**




Source: Dave Lee & Brian Lam , Research Department,
Metropolitan Transit Commission

**exhibit 3.10**

**Minnesota State Gasoline Distribution**



It is of interest to point out that during the height of the energy shortage, 60 additional buses were put into peak service in Minneapolis - St. Paul; an increase of approximately 7%. Given the overall increase in ridership of approximately 6.5% it is evident that there was an appreciable increase in off-peak ridership although not enough to warrant additional off-peak service.

**SUMMARY**

In summary, the 1999 ridership forecasts for Winnipeg Transit will require a reversal of recent trends, especially in terms of employment and population distribution characteristics. Also, the proposed exclusive bus lanes and busways are important elements in encouraging and attracting ridership. For the facilities proposed, the forecasted a.m. peak hour ridership is well within the capacity of such facilities.

Even with a 100% real increase in fuel costs, ridership is estimated to increase by between 10% and 20%. This is due to the fact that gasoline costs only account for a proportion of total automobile operating costs; the fact that many auto users are captive; the probability that many discretionary auto trips would be eliminated before auto work trips; the fact that automobiles are becoming more fuel efficient and thus the energy costs of travel would not be proportional to fuel price increases; and the likelihood that there would be increased ride-sharing activity.

Transit ridership is appreciably more sensitive to decreases in gasoline availaility than to fuel price increases and, although there would be a significant increase in ridership with an energy shortage, other options such as area wide ride-sharing services would be important in minimizing the adverse affects of gasoline shortages.

# 4. POTENTIAL TECHNOLOGIES

The objective of this chapter is to present a long list of the potential vehicle technologies that might be employed in Winnipeg and the infrastructure alternatives on which these vehicles could operate. The chapter is divided into two main sections, the first dealing with vehicle technologies and the second with infrastructure alternatives. Within this chapter the infrastructure consists primarily of the roadway or guideway on which the vehicles operate and does not include any power supply elements of the system. Power supply is considered to be an integral part of each vehicle technology and therefore is included in the discussion on vehicles.

## VEHICLE TECHNOLOGIES

A list of the potential vehicle technologies that might be employed in Winnipeg is presented in Exhibit 4.1. The listing first separates bus from fixed guideway vehicle types. The technologies are further categorized by type of motive power plant and by various power system alternatives for each type of power plant. A number of specific vehicle systems are then listed for each power system alternative. In all, 19 different vehicle technologies have been identified, ranging from the standard diesel transit bus which is in wide use across Canada to a bus powered by hydrogen fuel cells which is still in the conceptual stage of development.

This list of vehicle technologies is not exhaustive in the sense that all possible technologies have been presented. For example, any of the options which use alternative fuels could be combined with regenerative braking. In addition, each alternative vehicle technology could be used with various bus body types, such as the medium size Orion bus, the standard Flyer or GMC "new look" buses, the Advanced Design Buses (ADB's) now manufactured in the United States, and articulated or double-deck buses. The analysis in this section concentrates on standard size transit vehicles since it was felt that the performance of the alternative technologies relative to each other in

## exhibit 4.1

## Potential Systems - Vehicle Technologies

| TYPE | MOTIVE POWER PLANT | POWER SYSTEM ALTERNATIVES | SPECIFIC VEHICLE SYSTEMS |
|---|---|---|---|
| BUS | Diesel Engines | - standard diesel engine using diesel fuel | - standard Canadian urban transit bus |
| | | - diesel engine incorporating regenerative braking | - diesel/flywheel hybrid<br>- diesel/hydraulic accumulator hybrid |
| | | - diesel engine with partial substitution of other fuels for diesel fuel. Some modification to the engine may be required but it will still use a diesel cycle | - diesel/vegetable oil<br>- diesel/methanol fuel mixture<br>- diesel/propane or CNG with gaseous fuel added to the air stream |
| | | - diesel engine with total substitution of other fuels for diesel fuel. Some modification to the engine may be required but it would still use a diesel cycle | - methanol/ethanol fueled engine |
| | Alternative Fuel Engines | - spark ignition otto cycle engine similar to gasoline engine but with higher compression ratio | - propane, CNG or LNG powered engine<br>- hydrogen using cryogenic fuel storage |
| | | - K-cycle engine | - could be used with most petroleum and alcohol based fuels |
| | Electric Propulsion | - electric propulsion systems requiring the provision of full overhead wire infrastructure | - standard trolley coach<br>- standard trolley coach with regenerative braking |
| | | - electric propulsion systems requiring the provision of partial overhead wire infrastructure | - trolley/diesel<br>- trolley/battery<br>- trolley/flywheel |
| | | - electric propulsion systems which do not require any overhead wire infrastructure | - battery powered bus<br>- hydrogen fuel cell powered bus |
| FIXED GUIDE WAY | Electric Propulsion | - on-board D.C. traction motor with regenerative braking | - LRT vehicle |
| | | - linear induction motor with regenerative braking | - Intermediate Capacity Transit System (ICTS) |

terms of operating and cost characteristics would not change substantially for different bus body types.

Other technologies which have not been presented include the gas turbine engine and the Stirling engine. Prototype testing of an intercity bus powered by a gas turbine engine has been done in the United States. The main drawback of this type of propulsion system is that it increases fuel consumption by 15% in addition to being more expensive than a diesel engine. The Stirling engine is an external combustion engine which offers a potential efficiency similar to that of a diesel engine, but with reduced emissions and tolerance of a wide range of fuels. This engine is still under development in Sweden.

More complete descriptions of each of the vehicle technologies are presented in Appendix A. Each description includes:

1. A general discussion on the vehicle technology, how it works, and what energy source it uses.
2. The status of development of the technology, the availability of prototype or production models and the proposed timing of future developments.
3. Advantages and disadvantages of each technology relative to a standard diesel transit bus and/or a standard trolley coach.
4. Performance characteristics of the vehicle, such as acceleration, cruising speed, fuel efficiency relative to the characteristics exhibited by a standard diesel transit bus.
5. Power supply and infrastructure requirements.
6. Any available cost information.

Exhibit 4.2 presents a tabular summary of selected performance and cost characteristics for each of the alternative vehicle technologies.

## exhibit 4.2-1

## Alternative Vehicle Technology

/EHICLE TYPE: STANDARD BUS WITH PORTABLE FUEL ENGINE

| POWER UNIT | AVERAGE ACCELERATION $m/s^2$ | NORMAL DECELERATION $m/s^2$ | CRUISING SPEED km/h | FUEL/POWER CONSUMPTION | | CAPITAL COST | | OPERATING COST | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LITRES/ 100 KM | mJ/km | TOTAL | ANNUALIZED OVER LIFE | FUEL $/KM | MAINTENANCE $/KM | |
| STANDARD CANADIAN URBAN DIESEL BUS | 1.0 | 1.0 | 70-90 | 45-70 1/100 km | 19-30 | $140,000 | $12,600 | .20 | .24 | |
| DIESEL/FLYWHEEL HYBRID | Similar to above | Similar to above | Similar to above | Expected Saving of 20-30% | - | n.a. | - | .16 | .28-.38 | Volvo has built prototype, but friction losses negated the benefits of regenerative braking |
| DIESEL/HYDRAULIC ACCUMULATOR | Similar to above | Similar to above | Similar to above | Expected saving of 25% | - | $165,000 | $14,500 - $15,000 | .16 | .27 | Prototype vehicle under testing |
| DIESEL/VEGETABLE OIL ENGINE | Same as Conventional | Similar to above | Similar to above | Same loss in efficiency | - | $145,000 | $13,000 | .23 Estimate | .26 | Fuel cost assumes 30% substitution and 15% efficiency loss |
| DIESEL/METHANOL FUEL MIXTURE | Same as Conventional | Similar to above | Similar to above | Same improvement in effi- | - | $145,000 | $13,000 | .19 Estimate | .25 | Fuel cost assumes 20% substitution and 5% efficiency improvement |

## exhibit 4.2-2

## Alternative Vehicle Technology

VEHICLE TYPE: STANDARD BUS WITH PORTABLE FUEL ENGINE

| POWER UNIT | AVERAGE ACCELERATION $m/s^2$ | NORMAL DECELERATION $m/s^2$ | CRUISING SPEED km/h | FUEL/POWER CONSUMPTION | | CAPITAL COST | | OPERATING COST | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LITRES/ 100 KM | mj/km | TOTAL | ANNUALIZED OVER LIFE | FUEL $/KM | MAINTENANCE $/KM | |
| DIESEL/PROPANE OR CNG | Slightly Improved Acceleration | Similar to above | Same as Conventional | Some loss in efficiency | - | $147,000 | $13,200 | Increase Expected | Slight Increase Expected | Developed for intercity trucks as a supplement to get a higher power without smoke |
| DIESEL ENGINE FUELED PRIMARILY BY METHANOL OR ETHANOL | Similar to Conventional | Similar to above | Same as Conventional | Similar efficiencies expected | - | $145,000 | $13,000 | Similar to diesel | Decrease versus diesel | Fuel mixture of 15-25% diesel, remainder methanol/ ethanol. Diesel used for ignition |
| PROPANE OR CNG POWERED ENGINE | Similar to Conventional | Similar to above | Same as Conventional | 10-20% Loss of efficiency on BTU basis | - | $135,000 | $12,200 | .22 | .24 | Heavy duty propane engines are not widely available |
| HYDROGEN POWERED ENGINE | n.a. | n.a. | n.a. | n.a. | - | n.a. | - | - | - | Concept development presently underway at UTDC |
| K-CYCLE ENGINE | n.a. | n.a. | n.a. | 30-40% improvement in efficiency claimed | - | n.a. | - | .13-.16 (Estimate) | | Engine under continuing development. Prototypes have have been tested. |

## exhibit 4.2 -3
## Alternative Vehicle Technology

VEHICLE TYPE: STANDARD BUS WITH ELECTRIC POWERED MOTOR

| POWER UNIT | AVERAGE ACCELERATION $m/s^2$ | NORMAL DECELERATION $m/s^2$ | CRUISING SPEED km/h | FUEL/POWER CONSUMPTION | | CAPITAL COST | | OPERATING COST | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Kwh/ 100 KM | mj/km | TOTAL | ANNUALIZED OVER LIFE | FUEL $/KM | MAINTENANCE $/KM | |
| STANDARD TROLLEY COACH (WITH CHOPPER OR PWM (A.C.) CONTROL) | 1.0-1.6 | 1.0 | 60-68 | 210 kWh/100 km | 8 | $200,000 per vehicle $400,000 per route km | $12,300 per vehicle $23,100 per route km | .06 | .19 per vehicle $4,000 per route km | Chopper control is becoming the industry standard |
| STANDARD TROLLEY COACH WITH REGENERATIVE BRAKING AND CHOPPER CONTROL | As Above | As Above | As Above | 150-180 kWh/100 km | 5-6 | $210,000+ power supply | $12,300 | .04-.05 | Slightly Higher vehicle costs | Regenerative braking is being applied more widely |
| TROLLEY COACH WITH AUXILIARY DIESEL OR GASOLINE ENGINE | As Above | As Above | Reduced | Depends on duty cycle approx. 10% higher energy requirements | - | $250,000+ power supply | $15,400 | Depends on % Overhead Wire | Higher vehicle, cost lower power supply | Based on an application in Esslingen, West Germany, the total annual cost of the trolley coach/diesel bus is approx. 1.2 times the cost of a diesel bus |
| TROLLEY COACH WITH AUXILIARY BATTERY POWER (FULL OFF-WIRE SERVICE) | Reduced Performance as a Result of Increased Weight | As Above | Reduced | Depends on duty cycle up to 30% higher than trolley | - | $250,000 | Estimated at 1.7 times Trolley + Power Supply | Estimated at .08 | Higher | Based on an application in Esslingen, West Germany, the total annual cost of the trolley coach/battery bus is approx. 1.4 times the cost of a diesel bus |
| (EMERGENCY OFF-WIRE CAPABILITY) | 1.0 | 1.0 | 60-68 | 210 | 8 | $210,000 | $12,900 | .06 | Marginally Higher | |

## exhibit 4.2-4

## Alternative Vehicle Technology

VEHICLE TYPE: STANDARD BUS WITH ELECTRIC POWERED MOTOR

| POWER UNIT | AVERAGE ACCELERATION $m/s^2$ | NORMAL DECELERATION $m/s^2$ | CRUISING SPEED km/h | FUEL/POWER CONSUMPTION | | CAPITAL COST | | OPERATING COST | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Kwh/ 100 KM | mj/km | TOTAL | ANNUALIZED OVER LIFE | FUEL $/KM | MAINTENANCE $/KM | |
| TROLLEY/ FLYWHEEL HYBRID | 1.0 - 1.6 | 1.0 | 70-90 | 225 kWh/100 km | 8 | $240,000 to $300,000 power supply (15% of trolley coach) | $14,800 to $18,500 power supply | .063 | 15% higher than trolley coach | All costs are based on estimates by Garrett as part of their flywheel trolley coach development program. An auxiliary heat source may be required under Winnipeg conditions |
| BATTERY BUS | 0.6 - 0.9 | n.a. | 65-70 | 280 | - | n.a. | Estimated 1.9 times trolley coach + charging facilities | .08 | Expected to be higher than trolley coach | The lifetime of a battery is only 50,000 km, after which time it must be replaced |
| HYDROGEN FUEL CELL | n.a. | n.a. | n.a. | n.a. | - | n.a. | - | - | - | This vehicle is in the conceptual stage of development and estimates of its characteristics won't be available for at least a year |

## exhibit 4.2-5

## Alternative Vehicle Technology

VEHICLE TYPE: FIXED GUIDEWAY VEHICLES

| POWER UNIT | AVERAGE ACCELERATION $m/s^2$ | NORMAL DECELERATION $m/s^2$ | CRUISING SPEED km/h | FUEL/POWER CONSUMPTION | | CAPITAL COST | | OPERATING COST | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Kwh/ 100 KM | MJ /KM | TOTAL | ANNUALIZED OVER LIFE | FUEL $/KM | MAINTENANCE $/KM | |
| LRT POWERED BY DC TRACTION MOTORS | 1.0-1.4 | 1.2-1.6 | 65-100 | 220-280 kWh/100 km | 8-10 | $700,000-$900,000 + $1,200,000 per km | $40,500 to $52,000 | .07 | .30 | |
| ICTS POWERED BY LINEAR INDUCTION MOTOR | 1.0 | 1.0 | 70 | Similar to LRT | - - | $800,000 to $1,000,000 | $46,000 to $58,000 | .07 | .42 | ICTS systems are being developed in Vancouver and Toronto |

The vehicle performance characteristics, acceleration, deceleration and cruising speed, were obtained from vehicle specifications and/or publications describing the various technologies. Often the performance of the technology was only described in a qualitative manner relative to standard diesel or trolley coach buses. The fuel/power consumption figures are based on actual data in the case of the diesel buses and trolley coaches. For the other vehicles, the values are based on test results, estimates or conclusions drawn by the developers of the various technologies.

Except in the case of the standard technologies, the capital cost figures are based primarily on estimates, both quantitative and qualitative, obtained from various reports describing the technologies. In cases where there was a large variation in the cost estimates, judgement was used to determine an appropriate average value. The cost estimates are in 1981 Canadian dollars. Due to the volatility of exchange rates and the existing high rate of inflation, these cost estimates should be used primarily as indicators of the relative costs of the technologies.

In order to estimate the annualized value of the capital costs the following assumptions were made:

- an amortization rate of 4% per year was used. This represents the expected real cost of money over the life of the vehicles;
- engine and body costs for the diesel and other fuel engine vehicles were annualized over 15 years;
- the costs of trolley coach propulsion systems and bodies were annualized over 25 years;
- the costs of fixed guideway vehicles were annualized over 30 years.

Fuel and energy cost estimates are based on a diesel fuel cost of $0.33/litre and an electricity cost of 2.8¢ per kWh (the industrial rate for electricity in Winnipeg is described in more detail in Appendix D).

The maintenance costs include items such as engines/motors, power driveline, brakes, suspension, body, tires, electrical components and inspection. The estimated cost per kilometre for the diesel bus is based on maintenance and servicing expenditures (excluding fuel and maintenance administration) made by City of Winnipeg Transit. In 1979 and 1980 the maintenance costs in Winnipeg were $0.20/km and $0.22/km respectively. In order to account for inflation a value of $0.24/km was used as the 1981 estimate. The maintenance cost for the standard trolley coach was set at 80% of the cost of the diesel bus or $0.19/km, based on the conclusions of Chase, Rosen and Wallace in their report on trolley coaches for the U.S. Department of Transportation. Qualitative statements are made about the maintenance costs of the other technologies relative to the costs of either diesel or trolley coach buses.

## ALTERNATIVE INFRASTRUCTURES

Almost all of the vehicle technologies as described in the previous section of this report can be operated on different types of infrastructures. There are three basic types of infrastructures, as follows:

- shared use of existing roadways, i.e. conventional operation in mixed traffic;
- restricted right-of-way operations, for example, exclusive bus lanes or separate lanes for LRT vehicles. In both cases the operations of the vehicles are governed by regular street signals;
- exclusive right-of-way operations, for example busways or transitways.

A transit route can consist of various combinations of these three types of infrastructures. For example, buses may operate on a regular street system during the feeder portion of their route, then travel on an exclusive busway for the line-haul portion, and finally serve the downtown core using lanes restricted to transit vehicles.

Exhibit 4.3 presents a summary of the passenger capacity and cost characteristics of the various infrastructures for standard bus, LRT and ICTS vehicles. As shown in the exhibit, the ICTS technology is presently designed to only operate on an exclusive right-of-way.

The capacities of each vehicle type when operating on the various infrastructures were defined as follows:

- the capacity per vehicle was set equal to the design capacity of the vehicle (both seated and standing) multiplied by the average operating speed;
- the maximum route capacity was defined as the maximum passenger demand which could be served under normal operating conditions using feasible headways.

The capital costs of infrastructure were assumed to be nil in the case of a bus operating on a shared use roadway, and included track work and power supply but not road surfacing in the case of a LRT in mixed traffic operations.

The costs of a restricted right-of-way infrastructure for buses include signage, painting and minor changes in road geometrics, while for LRT systems the costs reflect more extensive road work requirements in addition to tracks and power supply. The costs of providing exclusive rights-of-way for the different vehicle types depends to a large extent on the number of grade separations and tunnel sections required and on the type of roadway provided, i.e. at-grade or elevated. In all cases, the capital costs for LRT and ICTS systems include power supply costs. For these systems a power supply infrastructure is always required, whereas for bus operations power supply costs are dependent on the choice of vehicle technology.

The expected life of the infrastructures was assumed to be 30 years except in the case of exclusive bus lanes which were given a life of 15 - years. A 4% "real" amortization rate was used to determine the annualized cost of the infrastructure. This was based on recent experience with interest rates corrected for the effects of inflation.

## exhibit 4.3-1

## Alternative Infrastructures

INFRASTRUCTURE TYPE: NO SPECIAL INFRASTRUCTURE, I.E. CONVENTIONAL OPERATION IN MIXED TRAFFIC

| VEHICLE TYPE | AVERAGE OPERATING SPEED (km/h) | CAPACITY | | CAPITAL COST | | ANNUAL OPERATING AND MAINTENANCE COSTS | TOTAL ANNUAL COSTS | COMMENTS |
|---|---|---|---|---|---|---|---|---|
| | | PER VEHICLE | ROUTE | TOTAL | ANNUALIZED | | | |
| BUS | 20 | 1,600 passenger-km per hour (p-km/h) | 1,500-3,000 pphpd | No additional costs | - | No additional costs | - | Assumes that a bus route does not affect roadway design requirements |
| LRT | 20 | 2,800 (p-km/h) | 5,000-9,000 pphpd | $4.0 to 6.0 Million per double track km | $220,000 - $340,000 per km | $10,000 to $12,000 per route km | $230,000 to $350,000 per km | Capital and maintenance costs include power supply |
| ICTS | Cannot Operate Without Restricted Right-of-Way | | | | | | | |

## exhibit 4.3-2

## Alternative Infrastructures

INFRASTRUCTURE TYPE: RESTRICTED RIGHT-OF-WAY

| VEHICLE TYPE | AVERAGE OPERATING SPEED (km/h) | CAPACITY | | CAPITAL COST | | ANNUAL OPERATING AND MAINTENANCE COSTS | TOTAL ANNUAL COSTS | COMMENTS |
|---|---|---|---|---|---|---|---|---|
| | | PER VEHICLE | ROUTE | TOTAL | ANNUALIZED | | | |
| BUS | 30 | 2,400 p-km/h | 5,000 - 8,000 pphpd | $50,000 - $10,000 per km | $5,000 - $10,000 per km | $1,000 to $2,000 per km | $6,000 to $12,000 per km | Maintenance includes upkeep of painting and signs, but not roadway |
| LRT | 35 | 5,000 p-km/h | 8,000 - 12,000 pphpd | $6.0 to $20.0 Million per km | $345,000 - $1,155,000 per km | $40,000 to $50,000 per km | $400,000 to $1,200,000 per km | Capital and maintenance costs include power supply |
| ICTS | Presently Designed to Operate on Exclusive Right-Of-Way | | | | | | | |

## exhibit 4.3-3

## Alternative Infrastructures

INFRASTRUCTURE TYPE: EXCLUSIVE RIGHT-OF-WAY

| VEHICLE TYPE | AVERAGE OPERATING SPEED (km/h) | CAPACITY | | CAPITAL COST | | ANNUAL OPERATING AND MAINTENANCE COSTS | TOTAL ANNUAL COSTS | COMMENTS |
|---|---|---|---|---|---|---|---|---|
| | | PER VEHICLE | ROUTE | TOTAL | ANNUALIZED | | | |
| BUS | 40 | 3,200 - 4,000 p-km/h | 5,000 - 15,000 pphpd | $4.0 to $16.0 Million per km | $230,000 - $930,000 per km | $35,000 - $45,000 per km | $265,000 - $975,000 per km | Operating speed depends on station spacing |
| LRT | 40 | 5,500 - 7,000 p-km/h | 10,000 - 20,000 pphpd | $8.0 to $24.0 Million per km | $690,000 - $1,735,000 per km | $40,000 - $50,000 per km | $730,000 - $1,785,000 per km | Capital cost depends on grade separations and roadway type |
| ICTS | 40 | 4,000 - 5,000 p-km/h | 15,000 - 25,000 pphpd | $10.0 to $20.0 Million per km | $580,000 - $1,160,000 per km | $50,000 - $160,000 per km | $630,000 - $1,320,000 per km | Capital costs assume elevated roadway with some at grade sections |

Operating and maintenance costs include only those costs which would be additional to regular street maintenance costs. These costs include the maintenance of the power supply and signalling system for the LRT and ICTS alternatives.

The cost data presented in Exhibit 4.3 are based on previous work by IBI Group for the Regional Municipality of Ottawa-Carleton and for the Quebec Urban Community as well as actual costs incurred during the construction of the Calgary LRT. All are expressed in 1981 dollars.

## 5. SCREENING OF ALTERNATIVES

In Chapter 4 a large number of potential systems are listed and their characteristics defined. In this chapter these potential systems are screened to select the most promising ones for further evaluation in the Winnipeg context. The screening is done in three steps:

- a review of technologies to reject those systems which have not been developed to the extent that they can be considered for implementation over the horizon period of this project;
- a preliminary costing of the surviving technologies to eliminate those which appear to be significantly more costly without having other off-setting advantages;
- a summary of the most promising technologies from the remaining systems.

### TECHNOLOGY REVIEW

The material included in Chapter 4 describes the state of the technology development of the various systems. Exhibit 5.1 summarizes this information. Each technology is assigned to one of five categories:

1. Available and Proven - these are transit technologies which are commercially available today and have proven themselves in service in Canada. Only standard diesel buses, trolley coaches, trolley coaches with regenerative braking, and light rapid transit systems are included in this category.

2. Operational Prototypes Available - these are systems for which operational prototypes, that is vehicles designed for revenue service, have been constructed and tested in Canada or abroad. Systems in this category include diesel/propane and propane buses that have been developed in Europe, and trolley/battery and trolley diesel hybrids.

3. Developmental Prototypes Available: these are vehicles for which developmental prototypes have been designed and built or are in the process of being designed and built. These include the trolley/flywheel program in the United States, the diesel/hydraulic accumulator hybrid, diesel/methanol dual fuel buses, alcohol powered buses and battery buses using lead acid batteries.

## exhibit 5.1

## Status of Technology Development

| AVAILABLE AND PROVEN | OPERATIONAL PROTOTYPES AVAILABLE | DEVELOPMENTAL PROTOTYPES AVAILABLE | PROTOTYPES AVAILABLE WITHIN 2 - 3 YEARS | UNDER RESEARCH |
|---|---|---|---|---|
| - Standard diesel bus | - diesel/propane | - diesel/hydraulic accumulator | - diesel/flywheel | - hydrogen (both types) |
| - Standard trolley coach | - propane | - diesel/methanol | - diesel/vegetable oil | - K-cycle |
| - trolley with regenerative braking | - trolley/diesel | - methanol/ethanol | | - battery (sodium-sulphur) |
| - LRT | - trolley/battery | - trolley/flywheel | | - natural gas (CNG and LNG) |
| | | - battery (lead acid) | | |
| | | - ICTS | | |

4. Prototypes Available Within 2-3 Years: these are vehicles on which some developmental work is taking place. They include such vehicles as the diesel/flywheel bus being investigated by the UTDC under contract to Transport Canada and diesel buses that use vegetable oils as a dual fuel.

5. Under Research: these are vehicles which have not yet been constructed but which, on paper, have been or are being investigated. They include hydrogen buses, buses powered by a K-cycle engine, and battery buses using more advanced batteries such as the sodium-sulphur technology, and buses utilizing natural gas. In this last case it is the storage system for the natural gas which are under research rather than the vehicles themselves.

The vehicles in the last two stages of development are not considered further in this report. Their technology characteristics are not sufficiently well known to enable proper comparisons to be made. They are unlikely to be commercially available within the next ten years. In addition, the vehicle types in these two categories are all free running buses that do not require additional infrastructure. As such, they do not have system implications for Winnipeg Transit as they could replace, on a one for one basis, the existing diesel fleet; such decisions could be made five or ten years from now when reliable information is available.

The battery bus using lead acid batteries was also removed from further consideration for standard 40 foot buses. Although prototypes have been developed in Europe, experience to date has not been very satisfactory. To obtain a reasonable range, a heavy load of batteries has to be carried; these are often placed in a trailer. There is no North American program of research and development to improve this technology although some work is proceeding in Europe. There are also problems specific to Winnipeg in using lead acid batteries during cold periods. There may be, however, possibilities of using battery powered vehicles in special circumstances such as providing services within a small area where the speed and range restrictions are not a problem.

## PRELIMINARY COSTING

In this section the results of the preliminary costing used to evaluate the surviving systems are presented. The costing has been done in two steps:

- first, standard diesel buses have been compared with LRT and ICTS technologies. Because of the different vehicle sizes and because of the different rights-of-way required, this has been done on the basis of total costs including driver wages, vehicle costs and right-of-way costs;
- then the different bus systems are compared. Because equivalent size vehicles are used, all manned by one operator, and because the roadway requirements are similar or identical, this cost comparison includes only the operating and maintenance costs of the vehicles and motive power and the capital, operating and maintenance cost of any additional infrastructure required such as overhead wires, etc.

### Comparison Of Fixed Guideway Systems

The details of the cost comparison of the various fixed guideway systems are given in Appendix B. Exhibit 5.2 summarizes the results of various levels of capacity provided. It can be seen that for the volumes expected in any corridor in Winnipeg, the standard diesel bus has a substantial cost advantage over the alternative LRT and ICTS technologies. While these costs are very general in nature, the comparison indicates that, except in exceptional cases, these fixed route technologies would be much more expensive than ordinary diesel buses. The bus on street option cannot be compared directly to the bus on busway because, in the first case, no allowance is included for the value of the road space used by the buses.

When the route structure of Winnipeg Transit, with its many branches and direct service to downtown from almost all areas, is taken into consideration, the relative advantages of the bus technology becomes even more pronounced. A fixed guideway system would necessitate additional transfers for many passengers.

**exhibit 5.2**

## Comparison of Total Costs Per Place-Km.

| TYPE OF SYSTEM | CAPACITY PROVIDED IN PASSENGER-PLACES PER HOUR IN EACH DIRECTION | | |
|---|---|---|---|
| | 1,000 | 5,000 | 10,000 |
| | (cents per place-km in 1981 cents) | | |
| Bus on street - no road costs included | 2.9 | 2.9 | 2.9 |
| LRT on street - only track and power supply costs included | 8.0 | 3.3 | 2.7 |
| Bus on busway - including infrastructure costs | 23.6 | 6.4 | 4.2 |
| LRT on separate right-of-way - including infrastructure costs | 34.5 | 8.2 | 4.9 |
| ICTS - including infrastructure costs | 33.5 | 8.4 | 5.3 |

Therefore the focus on the remainder of the report is on alternative bus technologies and technologies that do not require large amounts of dedicated infrastructure.

## Comparison of Bus Systems

In this comparison all costing is done on the basis of cost per bus kilometre. The costs used in this analysis are only those that might vary with the technologies. They include fuel costs, maintenance costs and the annualized capital cost of the vehicle itself which do not vary with headway and the maintenance and annualized capital cost of power supply systems for the electric traction options which require at least some proportion of their routes equipped with overhead; the infrastructure costs are prorated on a vehicle-km basis although they vary with headway. The equations that were developed to produce these costs for different types of vehicle are explained in Appendix C.

The results of the analysis of the various electric bus options are shown in Exhibits 5.3 and 5.4 for current and future fuel prices respectively. Using current fuel costs, the diesel bus appears to be cheaper than the trolley alternatives with the potential exception of the trolley/flywheel. The trolley/flywheel analysis is based on operating characteristics as projected in the UMTA development program in the U.S.; for example, only 15% of the route length is expected to be equipped with overhead. By comparison the other two hybrids require 50% of their route lengths to be "wired". When future fuel prices are used, escalating the price of diesel fuel by 36% (from 33¢ to 45¢ per litre) and maintaining electricity charges constant, the trolley/flywheel appears better and the cost of the trolley coach with regenerative braking approaches the cost level of the various types of buses at close headways.

The headway used in these comparisons is the headway in the peak period. It also refers to the parts of the route equipped with overhead. In other words, for those electric vehicles which require only part of their

**exhibit 5.3**

## Comparison of Costs Using Current Fuel Prices

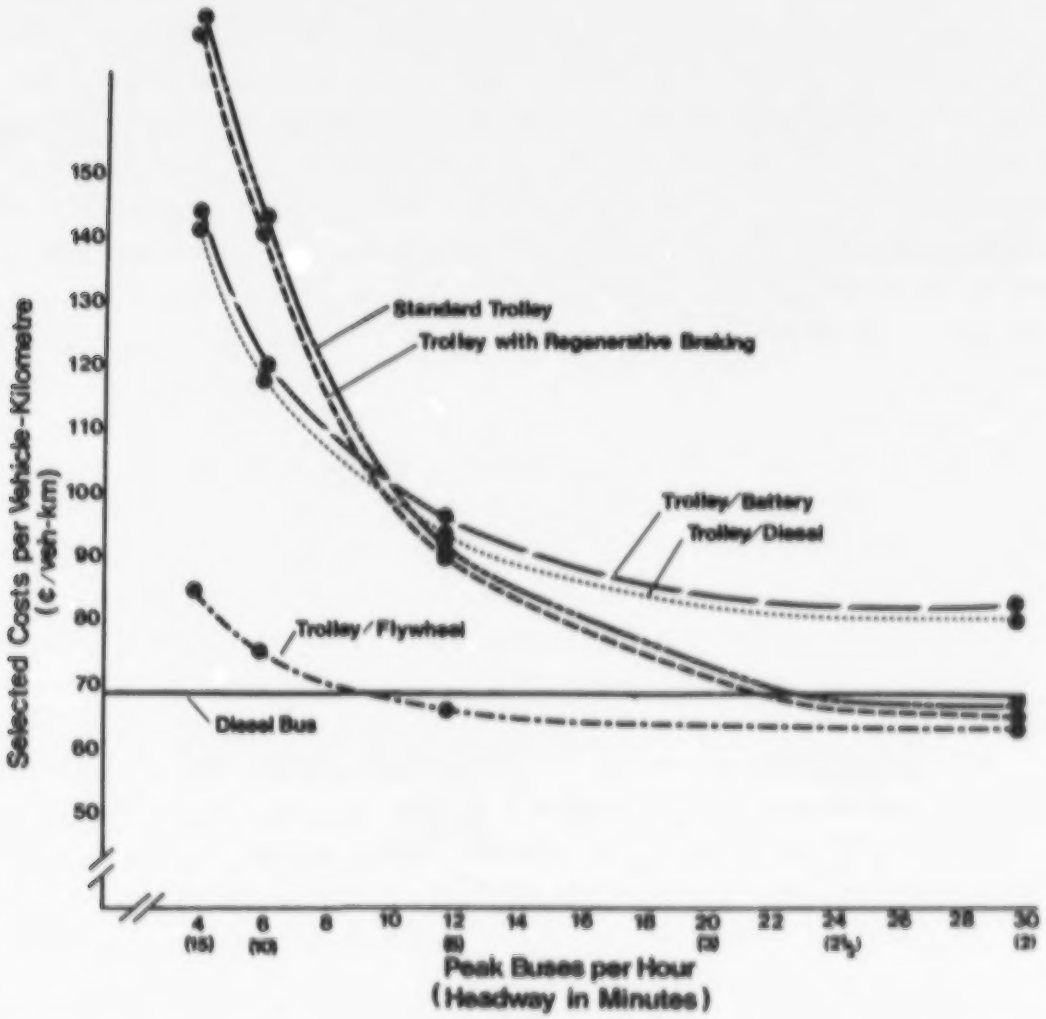
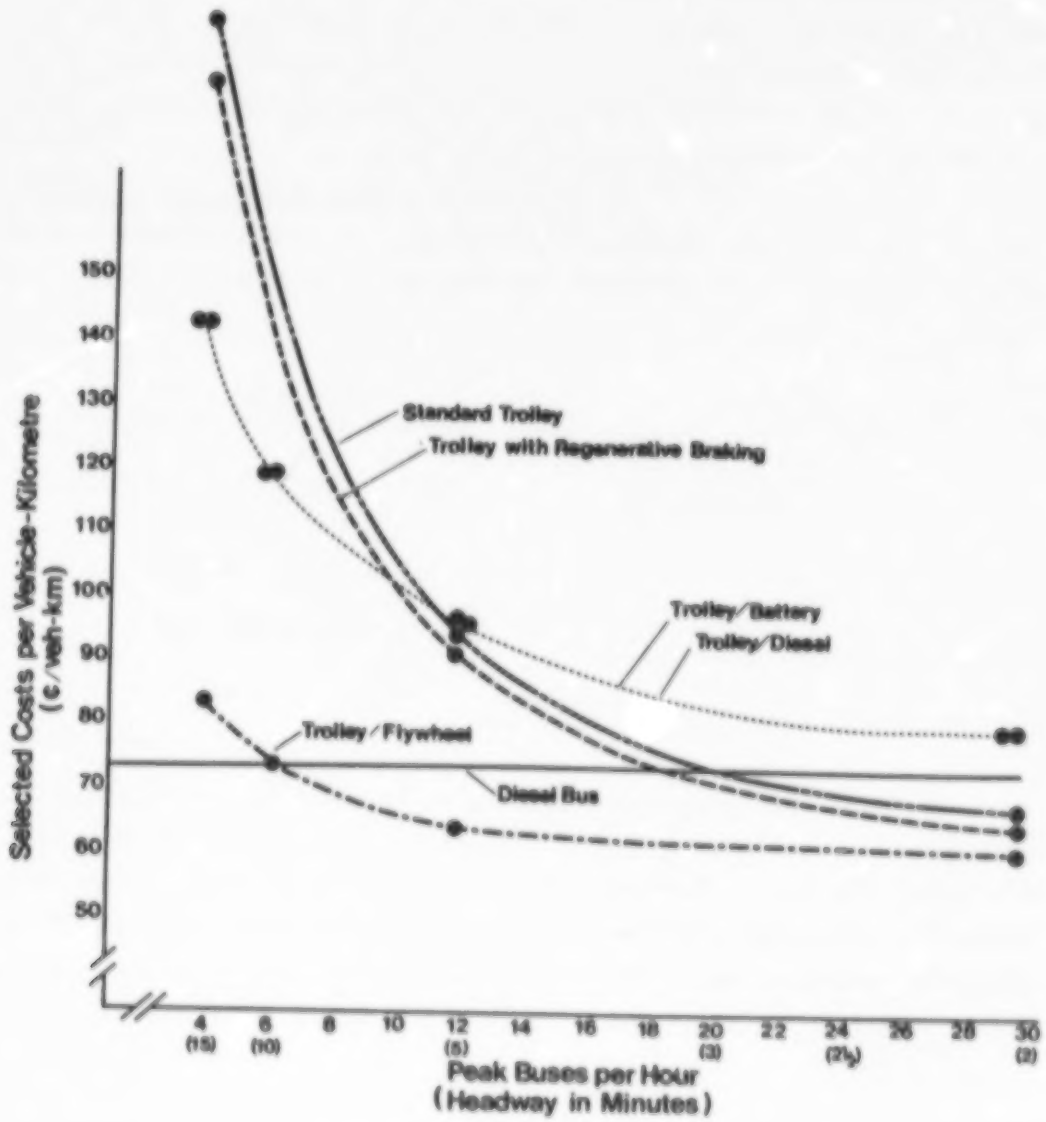


**exhibit 5.4**

**Comparison of Costs Using Future Fuel Prices**



route to be equipped with overhead, the headway which is relevant is that on the route sections which are equipped with power supply; this could be a common section for a number of routes.

Exhibit 5.5 compares the costs per vehicle/kilometre of the various portable fuel bus technologies. It can be seen that using current fuel prices the standard diesel appears to be the most advantageous. Using projected future fuel prices, methanol/ethanol and propane engines may have an advantage. It must be emphasized, however, that these are preliminary costs; they are refined in later chapters of this report.

Based on the results of this analysis, the following technologies were selected for more detailed examination in subsequent chapters of the report:

- all the various portable fuel bus technologies except the diesel/propane alternative. As can be seen in Exhibit 5.5, the technologies have costs which are so similar that the differences are not significant, given the preliminary nature of this costing;
- the trolley coach, assuming regenerative braking and chopper controls;
- the trolley/diesel hybrid;
- the trolley/flywheel hybrid.

At the present time, the trolley/battery hybrid does not have any apparent advantage and the battery technology needed is not well developed; therefore, the trolley/battery hybrid was eliminated from further consideration. This does not mean that having a battery on-board the bus for limited emergency movements would not be advantageous but that a system using battery power normally for part of the route does not appear to be practical.

**exhibit 5.5**

**Comparison of Portable Fuel Buses**

| VEHICLE SYSTEM | COSTS PER VEHICLE-KILOMETRE ($/VEH-KM) | |
|---|---|---|
| | USING CURRENT FUEL PRICES | USING FUTURE FUEL PRICES |
| Standard Diesel | 0.69 | 0.76 |
| Diesel/Hydraulic Accumulator | 0.72 | 0.78 |
| Diesel/Methanol | 0.71 | 0.75 |
| Diesel/Propane | 0.72 | 0.77 |
| Methanol/Ethanol | 0.72 | 0.72 |
| Propane | 0.71 | 0.76 |

The diesel/propane engine results in higher costs without providing a significant reduction in diesel fuel requirements and without lessening the demand for non-renewable resources. In addition, the use of this technology is primarily applicable to highway operations. For these reasons, this technology was judged to be unsuitable for transit applications and was not included in further analysis.

Although the diesel/methanol engine was included, it should be pointed out that, as with the diesel/propane technology, only moderate amounts of diesel fuel are saved by this technology and therefore the potential benefits of introducing this concept are limited.

## 6. ELECTRIC TRACTION OPTIONS

This chapter summarizes the major aspects of alternative operating plans for non-portable energy sources, namely service options which rely on electric power as the main source of energy. The objectives are:

- o to identify the most appropriate corridors for overhead wire for each electrical service option. This information was used to develop capital costs for each of the electrical options;
- o to estimate the investment and operating implications of different electric bus technologies and to compare them with a conventional portable fuel vehicle. Electrical energy requirements were estimated by time of day because energy costs can vary by time of day.

The service options considered were conventional trolley coaches powered from overhead lines, trolley coaches with off-wire diesel capabilities and trolley/flywheel vehicles. This last system reduces the need for overhead line requirements because the trolley can use the stored energy of the flywheel. For the trolley and trolley/diesel options, regenerative braking was considered in addition to regular braking. These systems have been described in previous chapters. Exhibit 6.1 summarizes the operating characteristics of the vehicle system considered. The trolley/diesel hybrid selected has only a small auxiliary motor and would have reduced performance characteristics when operating with diesel power; this is in line with current international practice with respect to standard size buses.

### IDENTIFICATION OF OVERHEAD WIRE REQUIREMENTS

Three separate overhead wire systems were developed: for the trolley coach, the trolley/diesel and for the trolley/flywheel. The basic aproach was to develop a network for a trolley coach system. Adjustments were then made to the trolley system to reflect the unique characteristics of the trolley/diesel and trolley/flywheel alternatives.

## exhibit 6.1

## Operating Characteristics of the Vehicle Systems Considered

| TECHNOLOGY | OPERATING CHARACTERISTICS | | | | | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|
| | ON-WIRE | | | OFF-WIRE | | | | |
| | ACCELERATION ($m/sec^2$) | CRUISING SPEED (km/h) | POWER/ CONSUMPTION kWh/km | ACCELERATION ($m/sec^2$) | CRUISING SPEED (km/h) | RANGE (km) | POWER/ CONSUMPTION kWh/km | |
| Option 1 (base) Diesel Bus | -- | -- | -- | 1.0 | 70-90 | 500 to 800 | 1.6-1.8 km/l | -- |
| Option 2 Trolley Coach With Chopper Controls and Regenerative Braking | 1.0 | 60 | 1.7 | -- | -- | -- | -- | Assumes 50% receptivity of line for regeneration |
| Option 3 Trolley/Diesel With Regenerative Braking | 1.0 | 60 | 1.8 | .25 | 40 | 50 to 200* | 1.0-1.4 | Vehicle must be parked when changing modes |
| Option 4 Trolley/Flywheel | 1.0 | 60 | 2.25 | 1.0 | 60 | 4-5 | 2.25 kWh/km | 90 sec. stationary recharge or 0.5 km in-line recharge every 4-5 km |

* depending upon tank size

In developing the trolley coach overhead wire system a number of factors were taken into account, including:

- Service Frequency: service frequency is an important factor in the suitability of a route for trolley service; the more frequent the service the lower the cost per vehicle-km of the fixed overhead wire cost. As a guide, all routes with 185 one-way trips a day were considered. Lower density routes were also considered if a major portion of the route was already provided with overhead wire for other routes. At some branch points, trolley wire was extended if it was considered impractical to implement a separate diesel feeder service.

- Historical Precedent: because Winnipeg Transit previously had trolley coach service, there is an historical reference point for trolley service. Routes which were previously served by trolleys were reviewed to determine their suitability for overhead wire in wire in light of changing demand patterns or expected changes in demand through to 1999.

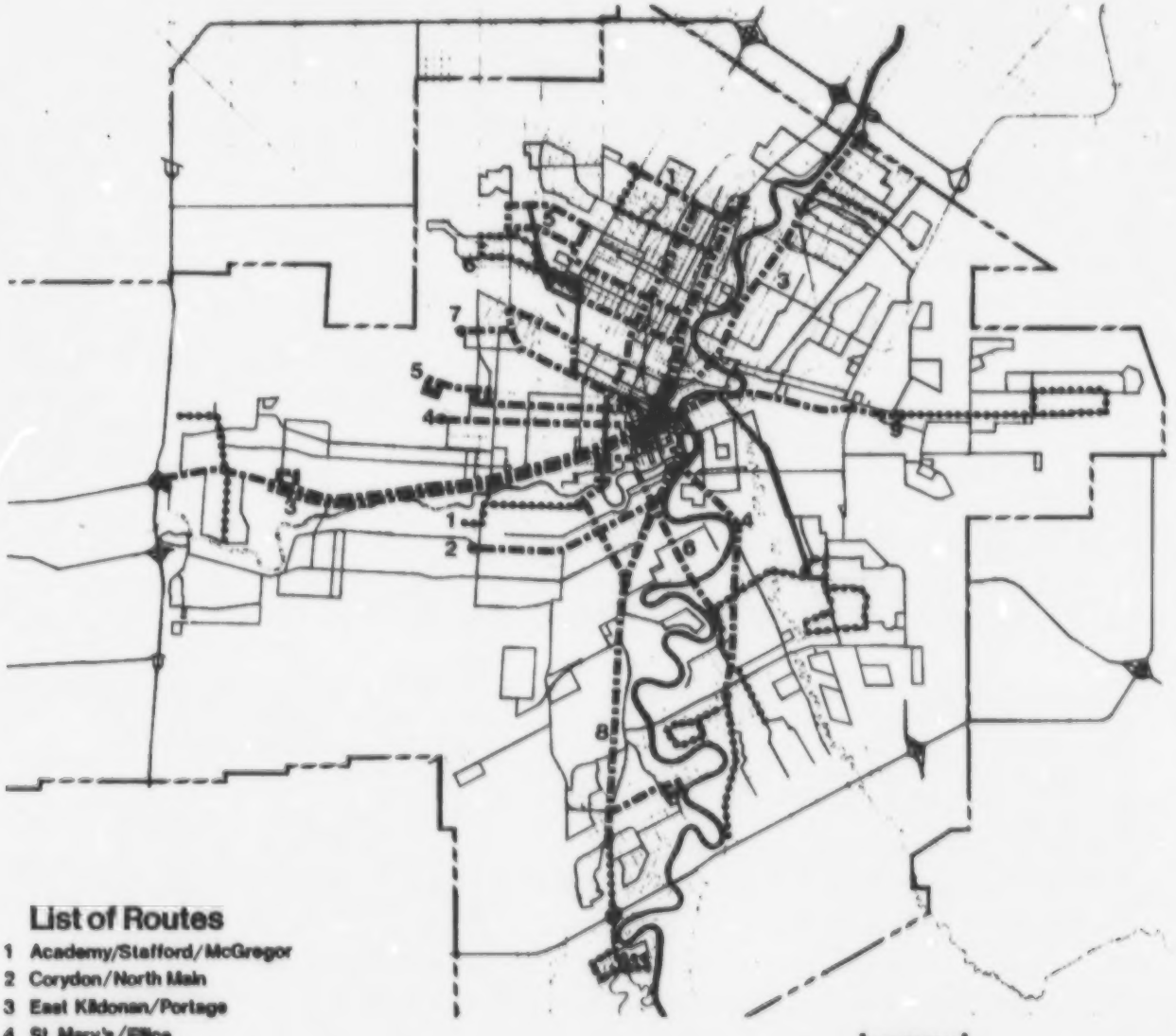
- Visual Compatibility: it was generally not considered appropriate to have overhead wire on local residential streets. Accordingly, most of the trolley overhead wire proposed would be constructed on major collectors and arterials.

- Length of Route: because of the concentration of trolley service in the downtown, most of the major downtown streets would have overhead wire. Accordingly, shorter routes operating out of the downtown were generally considered appropriate for trolley service.

Exhibit 6.2 illustrates the proposed overhead network for the trolley coach alternative, described as Option 2. Option 1 is the comparable diesel system. As shown on the exhibit, all of the major corridors leading out of the downtown area of Winnipeg would have overhead wiring in Option 2. These corridors include the busways adjacent to the Pembina Highway and along the CNR right-of-way east of the downtown to Regent Street; and the exclusive bus lane facility on Portage Avenue. On Portage Avenue two overheads would be required in each direction, one for the local transit service and one for express services. On the Henderson Highway it was assumed that local service would be provided by trolley coaches and the express service by diesel buses.

## exhibit 6.2

## Proposed Route Network for Conventional Trolley Coach with Diesel Feeder



In several areas of the city diesel feeder routes are required. Total peak service requirements tc serve the route system are 334 trolley coaches and 82 diesel buses.

The overhead requirements of the network developed for the trolley/diesel vehicles (Option 3) are illustrated in Exhibit 6.3. This network was designed to serve the same routes as Option 2, the conventional trolley coach operation. There are, however, several differences:

- to take advantage of the diesel capabilities of the vehicles, some of the overhead line on lightly used branches has been removed. Because of the limited performance characteristics of these vehicles when operating on the diesel engines, however, this has not been done on major arterial roads where reduced performance characteristics would be undesirable;

- because of the undesirable intrusion of wires on residential streets, the overhead network has been cut back and a diesel operation on these streets has been assumed;

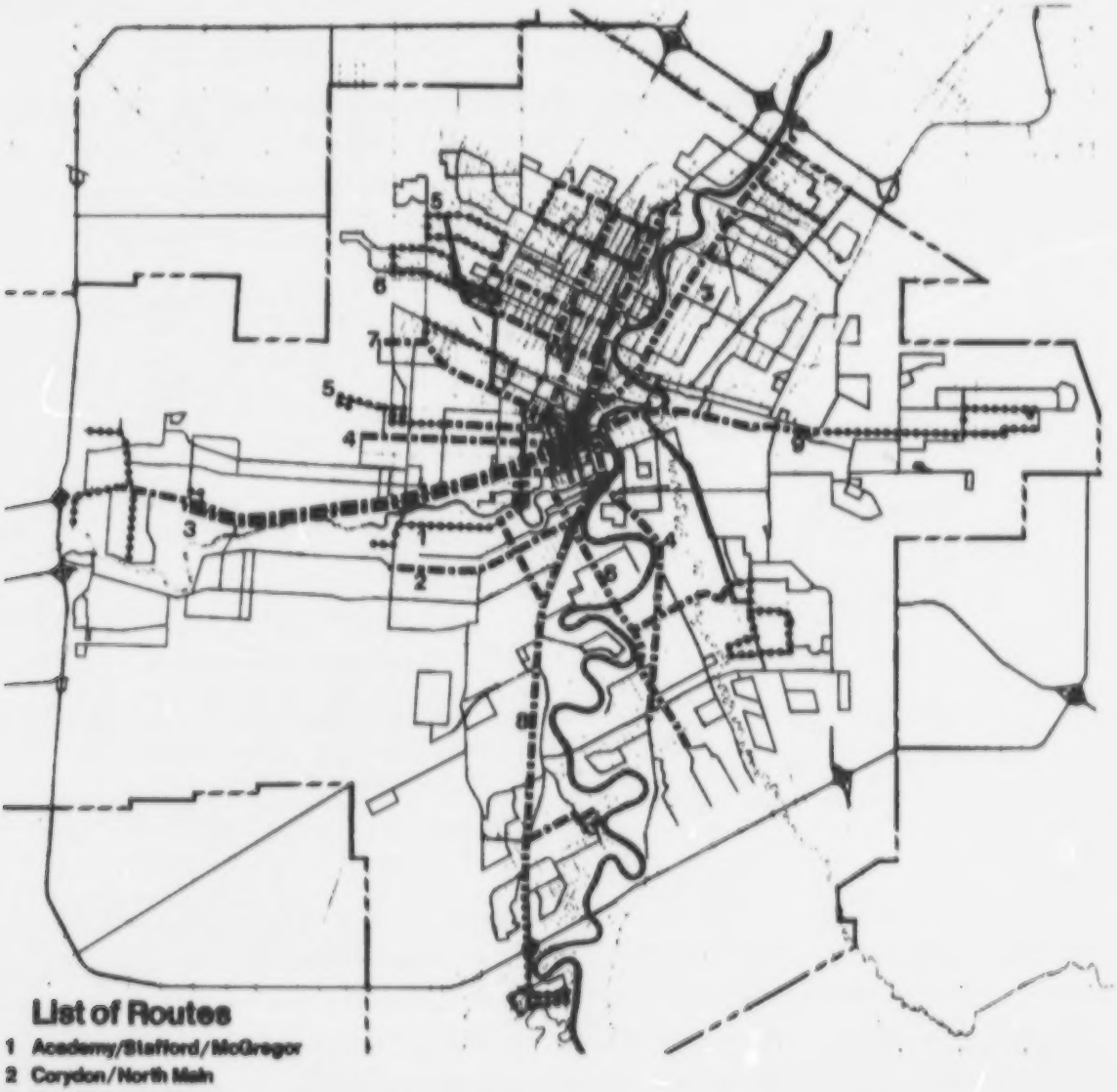
- in many cases where diesel feeder routes were provided in the trolley coach option, these have been replaced by through routes using overhead for the line haul portion of the journey and the diesel capability for the feeder part. In some cases, because of the relatively poor operating characteristics of the vehicle when using diesel power, this has resulted in extensions of the overhead.

The net result of all these changes is that the length of overhead for Option 3, the trolley/diesel system, has been reduced to 101 route kilometres from the 109 kilometres developed for Option 2, the conventional trolley coach operation. The number of feeder diesel buses has been reduced to 30 and the number of trolley/diesel vehicles increased to 386.

Exhibit 6.4 illustrates the overhead wire and recharging requirements for Option 4, the trolley/flywheel mode. As is evident in this exhibit, the overhead requirements have been reduced significantly. The miles of overhead for this option have been reduced to 32 route kilometres. It must be

**exhibit 6.3**

## Proposed Network for Trolley/Diesel Hybrid System




### List of Routes

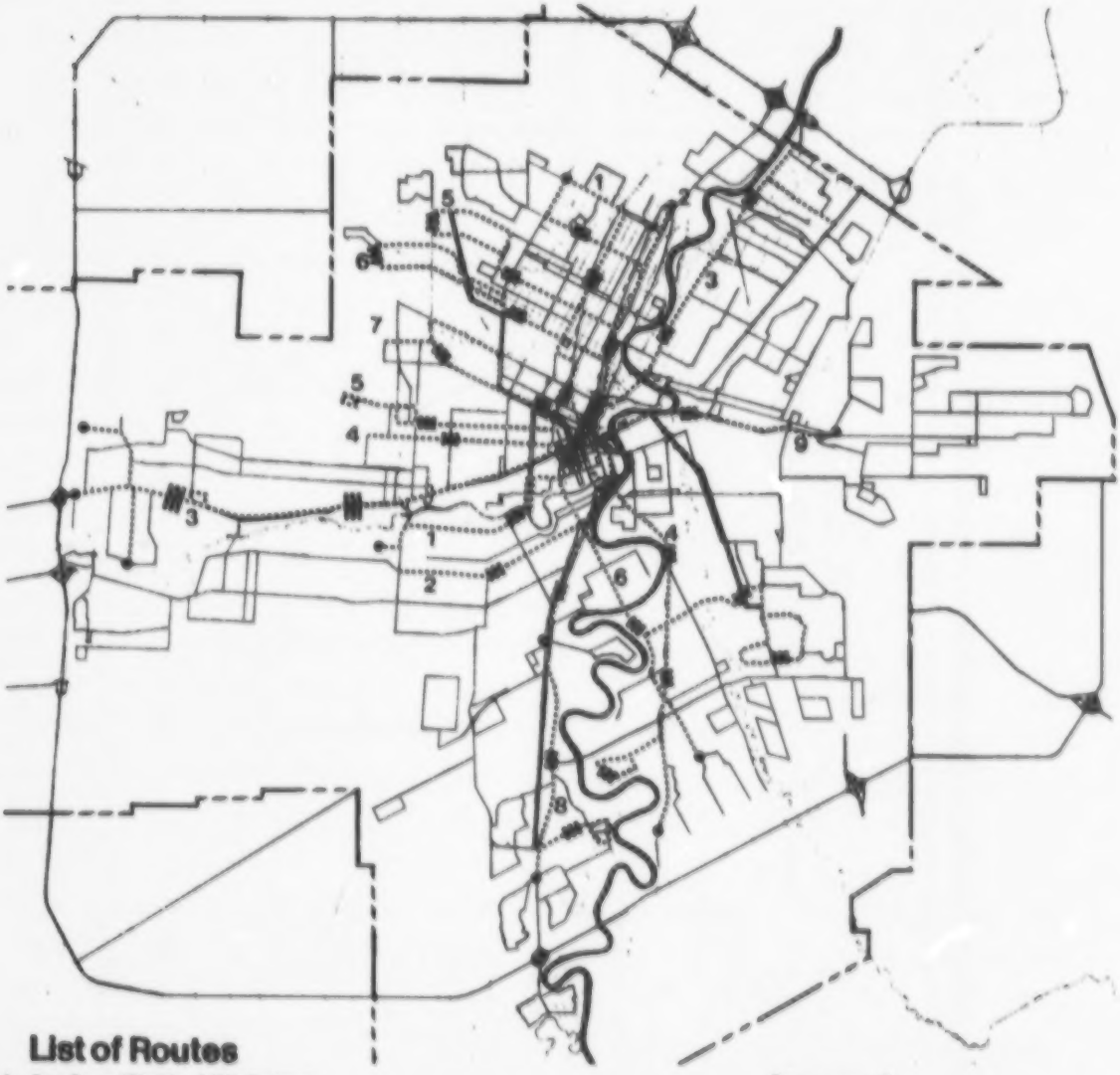
1 Academy/Stafford/McGregor
2 Corydon/North Main
3 East Kildonan/Portage
4 St. Mary's/Ellice
5 Mountain/Sargent
6 Osborne/Bellrk
7 Notre Dame/Logan
8 Southwestern Corridor/ King's Park
9 Eastern Corridor/Transcona

### Legend

Overhead trolley coach cables
Twin overhead cables for combined express and local service
Hybrid vehicles operating on diesel capability
Feeder bus system

**exhibit 6.4**

## Proposed Network for Trolley/Flywheel Hybrid System




### List of Routes

1 Academy/Stafford/McGregor
2 Corydon/North Main
3 East Kildonan/Portage
4 St. Mary's/Ellice
5 Mountain/Sargent
6 Osborne/Bellàrk
7 Notre Dame/Logan
8 Southwestern Corridor/ King's Park
9 Eastern Corridor/Transcona

### Legend

..... Routes serviced by trolley/flywheel vehicles

0.80 km (1/2 mi.) overhead cable recharge sections

0.40 km. (1/4 mi.) overhead cabled turnaround sections

Downtown route sections completely equiped with overhead cables.

## exhibit 6.5

## Summary of Overhead and Vehicle Requirements and Associated Costs

| | ESTIMATED CAPITAL COST FOR POWER SUPPLY ($'000) | DISTANCE OF OVERHEAD WIRE (ROUTE-KM) | COST/KM OF OVERHEAD ($'000) | NUMBER OF BUSES REQUIRED FOR SERVICE* | SPARES | CAPITAL COST OF BUSES ($,000) |
|---|---|---|---|---|---|---|
| Option 1: Diesel | - | - | - | 416 | 42 | (@ $140) = $ 64,120 |
| Option 2: Trolley Coach | $45,110 | 109 | $414 | 334 | 34 | (@ $200) = $ 73,600 |
| | | | | 82** | 8 | (@ $140) = $ 12,600 |
| | | | | | | $ 86,200 |
| Option 3: Trolley/Diesel | $39,730 | 101 | $393 | 386 | 39 | (@ $220) = $ 93,500 |
| | | | | 30** | 3 | (@ $140) = $ 4,620 |
| | | | | | | $ 98,120 |
| Option 4: Trolley/Flywheel | $19,655 | 32 | - | 416 | 42 | (@ $270) = $123,660 |

NOTES: * Only applies for those routes that would have trolley coach. The total estimated Winnipeg Transit fleet is 837 buses (1999)

** Diesel buses used for feeder and Henderson Express services.

emphasized that this requirement is based on the assumed operating characteristics as claimed by the developers of the trolley/flywheel vehicles in the United States. Although some routes which did not have overhead in either of the previous two alternatives were considered appropriate for the trolley flywheel because of the marginal additional requirements, they were not considered in the subsequent comparison of operating systems; these additional routes only have five peak period vehicles and would have had only a marginal impact on the overall comparison. Therefore, to keep the systems comparable these additional routes were not considered further.

Exhibit 6.5 summarizes the overhead wire requirements and costs for each of the three electrical options. As would be expected, the capital cost of overhead is lowest for Option 4, the trolley/flywheel option, at approximately $20 million and most expensive for Option 2, the standard trolley coach, at $45 million. The trolley/diesel system, Option 3, has somewhat lower capital costs for overhead because of the shorter network but also because turnaround overhead is not required at terminals since it was assumed that the vehicle could turnaround using diesel power. These capital costs are based on the reuse of any poles that are available. A system utilizing completely new poles would require approximately $1.3 million additional capital costs for Options 2 and 3 and approxiately $250,000 for Option 4. More detail on the derivation of these costs is included in Appendix D.

Exhibit 6.5 also includes the estimated number of buses required for each service option and their estimated capital costs. It should be noted that the numbers of vehicles refer only to the fleet needed to serve the identified potential trolley coach system. The remainder of the system was assumed to continue to be served by standard diesel coaches or other portable fuel vehicles. Because Options 2 and 3 require diesel feeders to provide the same coverage as either of Options 1 or 4, the diesel bus requirements and costs of these feeder routes are included. The diesel bus option is the least costly in terms of total vehicle capital costs because of the lower unit cost of diesel buses. The trolley/flywheel option has the highest vehicle capital costs. For all options, a 10% allowance for spare vehicles was included.

## ENERGY CONSUMPTION REQUIREMENTS

Energy consumption estimates were developed for each of the alternatives including the diesel system, considering only those parts of the Winnipeg Transit system that might be served by trolley coaches. Because electrical costs are a function of time of day usage and peaking characteristics, time of day energy requirements were required. The following provides a brief summary of the steps applied in estimating time of day energy requirements for each of the alternatives including trolley and trolley/diesel with regenerative braking. The procedure included:

- deriving an adjustment factor for the 1999 EMME ridership estimates. The factor was based on the assumption that real fuel prices would increase by 35% by 1999 (taking into account the revised Alberta/Federal Government agreement on energy pricing) which would increase ridership by approximately 6%. An additional factor of 1.10 was applied to the a.m. peak hour work trips of the EMME model to translate the a.m. peak hour work trips to a.m. peak hour total trips. Combining these results in an overall factor of 1.17;

- the 1999 maximum load point ridership of the EMME model was adjusted by the factor derived above and vehicle requirements were developed taking into account loading standards and route itinerary times;

- vehicle distances for the a.m. peak hour were derived based on the route itinerary distance and the service frequency;

- the a.m. peak hour was used as a base to which other factors were applied to derive vehicle travel by hour by time of day;

- the energy requirements for each of the alternatives were developed.

In comparing each of the options with the entire Winnipeg Transit system, trolley coach operations in Option 2 would account for approximately 39% of the total system vehicle-kilometres of travel and trolley/diesel

(Option 3) and trolley/flywheel (Option 4) vehicles would account for 45% and 48% of system vehicle-kilometres, respectively. However, the trolley/diesel option would have the least amount of service powered by electricity, 38% of the service. By this comparison, the trolley/flywheel option provides the greatest opportunity to reduce diesel fuel consumption.

Winnipeg Hydro indicated that the price of power will vary not only with total use but also with peak demand as the peak demand determines the generation and line capacity required. Exhibit 6.6 provides a summary of electrical power requirements by time of day for each of the options. The higher power requirement occurs during the p.m. period between 3:30 and 5:30 when approximately 19% of the entire energy would be required. The other peak period occurs between 7:30 and 8:30 a.m.. The formula supplied by Winnipeg Hydro for the price to industrial users is 1.12¢ per kWh and $4.30 per kVA for peak demand in the month. On the basis of these charges and the expected demand as shown on Exhibit 6.6 the average energy charge works out to 2.93¢ per kWh. This compares with 1.94¢ per kWh which is the average rate charged to industrial users in Manitoba in 1981.

Exhibit 6.7 provides an estimate of the annual energy requirements and associated cost for each option. These are developed on two bases, using current fuel prices and future fuel prices. Current diesel fuel prices are assumed to be $.33/litre for diesel fuel; electrical costs are based on the formula described above. Future costs are based on diesel costs of $.45/litre with electrical power costs held constant as discussed previously.

## ANNUAL COSTS

Exhibit 6.8 summarizes the estimated annual costs for each of the four options. These costs are based on capital and operating costs that would vary by each option and do not include common costs such as driver wages,

**exhibit 6.6**

## Electrical Energy Requirements by Time of Day

| TIME PERIOD | OPTION 2 TROLLEY COACH (kWh per hour) | OPTION 3 TROLLEY/ DIESEL (kWh per hour) | OPTION 4 TROLLEY/ FLYWHEEL (kWh per hour) |
|---|---|---|---|
| 4:30 a.m. - 5:30 a.m. | 570 | 580 | 920 |
| 5:30 a.m. - 6:30 a.m. | 4,310 | 4,360 | 6,920 |
| 6:30 a.m. - 7:30 a.m. | 9,450 | 9,560 | 15,170 |
| 7:30 a.m. - 8:30 a.m. | 10,530 | 10,630 | 16,900 |
| 8:30 a.m. - 9:30 a.m. | 7,170 | 7,250 | 11,520 |
| 9:30 a.m. - 10:30 a.m. | 4,420 | 4,470 | 7,100 |
| 10:30 a.m. - 11:30 a.m. | 4,550 | 4,600 | 7,300 |
| 11:30 a.m. - 12:30 p.m. | 5,140 | 5,200 | 8,260 |
| 12:30 p.m. - 1:30 p.m. | 5,380 | 5,430 | 8,640 |
| 1:30 p.m. - 2:30 p.m. | 5,140 | 5,200 | 8,260 |
| 2:30 p.m. - 3:30 p.m. | 6,210 | 6,290 | 9,990 |
| 3:30 p.m. - 4:30 p.m. | 11,100 | 11,210 | 17,820 |
| 4:30 p.m. - 5:30 p.m. | 10,770 | 10,880 | 17,280 |
| 5:30 p.m. - 6:30 p.m. | 8,260 | 8,350 | 13,250 |
| 6:30 p.m. - 7:30 p.m. | 3,830 | 3,870 | 6,150 |
| 7:30 p.m. - 8:30 p.m. | 3,230 | 3,270 | 5,190 |
| 8:30 p.m. - 9:30 p.m. | 3,230 | 3,270 | 5,190 |
| 9:30 p.m. - 10:30 p.m. | 2,990 | 3,020 | 4,790 |
| 10:30 p.m. - 11:30 p.m. | 2,160 | 2,180 | 3,460 |
| 11:30 p.m. - 12:30 p.m. | 2,030 | 2,050 | 3,260 |
| 12:30 p.m. - 1:30 a.m. | 1,800 | 1,820 | 2,880 |
| DAILY TOTAL | 112,270 | 113,490 | 180,250 |

## exhibit 6.7

## Estimated Annual Energy Requirement for Services Affected by Electrification

| | DIESEL FUEL (THOUSANDS OF LITRES) | ELECTRICITY (THOUSAND kWh) | MOTIVE POWER ENERGY COST AT CURRENT PRICES* (1981 $,000) | MOTIVE POWER ENERGY COST AT FUTURE PRICES** (1981 $,000) |
|---|---|---|---|---|
| Option 1: Diesel | 13,027 | - | 4,299 | 5,862 |
| Option 2: Trolley Coach | 2,290 | 33,190 | 1,727 | 2,002 |
| Option 3: Trolley/Diesel | 3,260 | 33,550 | 2,057 | 2,448 |
| Option 4: Trolley/Flywheel | - | 33,282 | 1,562 | 1,562 |

NOTES: * Diesel fuel @ 33¢/litre and electricity @ 1.12¢/kWh and 4.30¢/kVA

** Diesel fuel @ 45¢/litre and electricity @ 1.12¢/kWh and 4.30¢/kVA

## exhibit 6.8

## Estimated Total Annual Costs in Constant 1981 Dollars

| | AMORTIZATION OF CAPITAL | | VEHICLE MAINTENANCE ($'000) | ELECTRICAL SYSTEM MAINTENANCE ($'000) | FUEL PRICE LEVEL | MOTIVE POWER ENERGY PURCHASE ($'000) | VEHICLE HEATING FUEL PURCHASE ($'000) | TOTAL ($'000) |
|---|---|---|---|---|---|---|---|---|
| | INFRASTRUCTURE ($'000) | VEHICLES ($'000) | | | | | | |
| Option 1: Diesel | - | 5,767 | 5,675 | - | Current<br>Future | 4,299<br>5,862 | -<br>- | 15,741<br>17,304 |
| Option 2: Trolley Coach | 2,887 | 5,845 | 4,806 | 1,063 | Current<br>Future | 1,727<br>2,002 | -<br>- | 16,328<br>16,603 |
| Option 3: Trolley/Diesel | 2,543 | 6,400 | 5,223 | 1,063 | Current<br>Future | 2,057<br>2,448 | -<br>- | 17,286<br>17,677 |
| Option 4: Trolley/ Flywheel | 1,258 | 7,915 | 5,912 | 289 | Current<br>Future | 1,562<br>1,562 | 384<br>579 | 17,320<br>17,515 |

NOTES: Capital costs were estimated at 4% real interest cost.
Economic life of overhead, substation and trolley vehicles was estimated to be 25 years. The economic life for diesel buses was assumed to be 15 years.
Current fuel prices: diesel - 33¢/litre
electricity - 1.12¢/kWh and 4.30¢/kVA of maximum demand
propane for heating - 20¢/litre

Future fuel prices: diesel - 45¢/litre
electricity - 1.12¢/kWh and 4.30¢/kVA of maximum demand
propane for heating - 27¢/litre

etc. It should be pointed out that capital costs were discounted at a rate of 4% to reflect real interest costs. The 4% rate was derived as being the approximate real interest rate for Government borrowing after taking into account inflation. Some economists would argue that rate used should be higher and set at the value of the best alternative use of the money.

The annual vehicle costs were based on the estimated vehicle requirements by type as summarized in Exhibit 6.5. It is important to point out that the economic life assumed for all trolley vehicles was 25 years as opposed to 15 years for diesel buses. This amortization period offsets, to some extent, the higher incremental costs of vehicles for the other options. It is, however, evident, that the most expensive annualized vehicle costs are for the trolley/flywheel option; approximately 37% higher than the diesel bus costs.

The vehicle maintenance costs were estimated on the basis of 24¢ per vehicle kilometre for diesel buses, 19¢ per kilometre for trolley coaches, 21.5¢ per vehicle kilometre for trolley/diesel and 25¢ per vehicle kilometre for trolley/flywheel, as described in Chapter 4 and Appendix A.

The electrical system maintenance costs were developed as described in Appendix D. Essentially the cost was based upon a minimum size crew being required. As the system is expanded larger numbers of maintenance staff are required. The maintenance costs therefore include a high fixed amount but depend also on the length of overhead wire in place. For this reason, the diesel/flywheel option is the least expensive, with only minor differences in the annual costs for overhead maintenance between Options 2 and 3.

The vehicles used for Options 1, 2 and 3 all have on-board heating capabilities using either waste heat from the diesel engines, or electrical power from regeneration while braking or from the overhead line; however, the

trolley/flywheel vehicle recaptures most of the mechanical energy of braking and is not normally connected to an overhead power line. Accordingly on-board heaters would probably have to be installed with an associated heating cost requirement. Exhibit 6.8 indicates that the cost of heating the trolley/flywheel vehicles would be approximately $579,000 per year at future fuel prices. This cost is based on using propane as the heating fuel at a price of $.27/litre.

Using current fuel prices the diesel system is least expensive in total. Using future fuel prices, the trolley coach option has the lowest annual operating costs, whereas the trolley/diesel has the highest annual cost. The two systems are equivalent in annual cost when the price of diesel fuel is approximately 38.5¢ per litre. Prices somewhat higher than 45¢ per litre for diesel fuel are required to make the other two options (Options 3 and 4) economically viable compared to the diesel bus.

## SENSITIVITY ANALYSIS

Exhibit 6.9 provides an analysis of the sensitivity of these results to changes in the interest rate assumed. At a 2% rate the trolley bus system is viable at current fuel prices. At a 6% interest rate it is slightly more expensive than the diesel alternative, even with diesel fuel at 45¢ per litre.

The other two options (Options 2 and 3) have higher annual costs than the diesel alternative at all interest rates tested and at both fuel prices.

## OTHER IMPLICATIONS

Exhibit 6.10 summarizes various other implications, in addition to costs, associated with each of the alternatives. With the exception of the trolley coach option (Option 2) each of the service options would have little

**exhibit 6.9**

## Sensitivity of Results to Changes in Interest Rates

| | TOTAL ANNUAL COSTS AT CURRENT FUEL PRICES ($000's of 1981 Dollars) | | TOTAL ANNUAL COSTS AT FUTURE FUEL PRICES ($000's of 1981 Dollars) | |
|---|---|---|---|---|
| | OPTION 1 DIESEL | OPTION 2 TROLLEY | OPTION 1 DIESEL | OPTION 2 TROLLEY |
| 2% Interest | | | | |
| Amortization | 4,990 | 7,061 | 4,990 | 7,061 |
| Maintenance | 5,675 | 5,869 | 5,675 | 5,869 |
| Fuel Costs | 4,299 | 1,727 | 5,862 | 2,002 |
| Total | 14,964 | 14,657 | 16,527 | 14,932 |
| 4% Interest | | | | |
| Amortization | 5,767 | 8,732 | 5,767 | 8,732 |
| Maintenance | 5,675 | 5,869 | 5,675 | 5,869 |
| Fuel | 4,299 | 1,727 | 5,862 | 2,002 |
| Total | 15,741 | 16,328 | 17,304 | 16,603 |
| 6% Interest | | | | |
| Amortization | 6,602 | 10,584 | 6,602 | 10,584 |
| Maintenance | 5,675 | 5,869 | 5,675 | 5,869 |
| Fuel | 4,299 | 1,727 | 5,862 | 2,002 |
| Total | 16,576 | 18,180 | 18,139 | 18,455 |
| 8% Interest | | | | |
| Amortization | 7,491 | 12,593 | 7,491 | 12,593 |
| Maintenance | 5,675 | 5,869 | 5,675 | 5,869 |
| Fuel | 4,299 | 1,727 | 5,862 | 2,002 |
| Total | 17,465 | 20,189 | 19,028 | 20,464 |

## exhibit 6.10

## Other Implications

| | PASSENGER SERVICE | AESTHETICS | AIR POLLUTION | NOISE | OPERATIONS |
|---|---|---|---|---|---|
| Option 1: Diesel Coach | - no impact | - no impact | - the highest amount of emissions | - noisy | - none |
| Option 2: Trolley | - requires transfers to trolley buses | - major impact because of overhead | - would reduce exhaust bus emissions considerably | - trolley coaches quiet<br>- diesel feeders in residential areas noisy | - limited flexibility |
| Option 3: Trolley/Diesel | - minimal impact | - major impact because of overhead<br>- not as extensive as with Option 2 | - would reduce exhaust bus emissions considerably | - trolley quiet<br>- more noise when operating with diesel in residential areas | - somewhat limited flexibility |
| Option 4: Trolley/Flywheel | - no impact | - some impact because of overhead<br>- (can be minimized) | - would eliminate exhaust emissions | - quiet | - less limited flexibility |

or no impact on passenger services. In the case of the standard trolley option, some passengers would be required to transfer between the local diesel feeder and the trolley portion of the route. This could have a negative impact on ridership especially in the lower frequency service areas.

With the exception of the diesel bus service, all other options would have a detrimental effect on aesthetics. The most severe impact would be with the standard trolley option. The trolley diesel option would have a smaller impact because the overhead wiring would not be necessary in residential areas. The trolley/flywheel option would have the least impact of the electrical traction options because of the reduced overhead requirements and because the overhead could be located in areas where its visual impact might be minimized.

All of the electrical traction options would reduce vehicle emissions relative to the diesel bus option. The trolley/flywheel option would produce the least emission because it does not require off-wire diesel operation or diesel feeder service.

All of the electric traction options would reduce noise levels although the possible noise impacts of flywheel vehicles are not really known at this time. However, Options 2 and 3 would still have an appreciable noise impact on residential areas because of the diesel feeder or diesel mode of operations in these parts.

In terms of operations, the standard trolley service would provide the least flexibility and would be the most restrictive. For example, vehicles could not deadhead into service on the most direct corridor but would be required to follow the overhead routing. In addition, it would be necessary to schedule meets so that local diesel feeders and trolley services met at designated points. In addition, a traffic accident or power disruptions could severely disrupt the service because of the limited flexibility of trolley

coaches. The trolley/diesel and trolley/flywheel options offer considerably more flexibility than with Option 2; however, the vehicles could not be interchanged on regular diesel service routes and thus would impose a scheduling and dispatching constraint.

## SUMMARY

As discussed in this chapter, there is relatively little difference among the options in terms of total annual cost. The selection of an appropriate system should be made largely on the basis of other considerations. These are discussed further in Chapter 8. The next chapter describes the liquid fuel options.

# 7. LIQUID FUEL OPTIONS

In Chapter 5, a number of potential transit technologies were screened to select the most promising ones for further evaluation in the Winnipeg context. The results of the evaluation for those options which require electrical power supply infrastructure have been presented in the earlier sections of this report. This chapter elaborates the evaluation of liquid fuel options selected in Chapter 5. These options are:

- standard diesel;
- diesel/alcohol;
- propane;
- alcohol;
- diesel with hydraulic accumulator.

Each option is reviewed in terms of the status of development and availability of the technology, its potential energy efficiency, the availability of the required fuel(s) in Manitoba now and in the future, the safety of the option during operations and fueling and economic considerations. The cost estimates presented in this section are based on "future" fuel prices as explained previously and all prices are expressed in current (1981) dollars. The capital costs of the technologies are based on the assumption that the technology has been accepted by the transit industry and is a standard production model.

## STANDARD DIESEL

The diesel engine is well established in the transit and trucking industries. Because of its wide application it is mass produced with favourable production costs and availability. In addition, the engine has proven reliability and serviceability both in terms of available parts and trained mechanics. The diesel engine is continually undergoing minor improvements and adjustments, to increase its efficiency and/or its power output and to minimize its impact in terms of emissions, noise generation, etc.

This technology has been successful for a number of reasons, including:

- the engine operates with a relatively high thermal efficiency due to its high compression ratio;
- under high compression, diesel fuel is self-igniting and therefore the engine does not require an ignition system;
- diesel fuel has a high energy content and therefore provides long range without excessive storage requirements.

The major drawback of the standard diesel engine as an appropriate transit technology for Winnipeg is the availability, security and price of the fuel supply. Manitoba is not self-sufficient in crude oil and must obtain much of its diesel fuel from the other Western Provinces or from abroad.

The demand for diesel fuel is increasing more rapidly than the demand for other petroleum fuels. In addition, as Canadian crude costs are raised to world levels and as the proportion of Canadian crude oil originating from tar sands and other non-conventional sources increases, diesel fuel will become increasingly expensive to produce. Based on the Federal/Provincial Energy Pricing Agreement, the real price of diesel fuel is expected to increase by up to 35% in the next decade. Therefore the fuel cost of the standard diesel bus is expected to be $.27 per kilometre in 1981 dollars in the forecast year. Maintenance costs are expected to increase at approximately the rate of inflation and would therefore remain at $.24 per kilometre in constant dollars over the forecast period.

It was assumed that the capital cost of a standard "new look" type of urban transit bus would remain at $140,000 in 1981 dollars, or $.25 per kilometre annualized over 15 years at 4% and assuming an average vehicle use of 50,000 kilometres per year.

The safety of the standard diesel bus during operations and fueling is used as the base for comparing the performance of the other liquid fuel options.

**DIESEL/ALCOHOL**

In this option, diesel would be the primary fuel and an alcohol fuel, either methanol or ethanol, would be used as a partial substitute. Methanol has very limited solubility in diesel fuel and therefore would have to be emulsified into the diesel fuel prior to injection into the engine. Dry ethanol is completely soluble in diesel fuel but separates with as little as 1/2% water present. Therefore, an emulsion may be more practical in this case as well. For both alcohol fuels, concentrations of up to 30% by weight could be used in a standard diesel engine. In tests with a methanol/diesel fuel emulsion carried out by the Ontario Research Foundation (ORF) using inter-city trucks, the maximum level of substitution was obtained only at cruising speed in highway operations. Preliminary experience relating to smooth running at low load conditions suggested that the methanol should be reduced or eliminated under idling conditions. Therefore, in order to be applied in stop-and-go transit operations a sophisticated control system would be required to govern the proportion of alcohol in the fuel mixture. Further research is required before conclusions can be drawn on the feasibility and effectiveness of such a control system.

The partial substitution by alcohol fuels would increase to a small extent the security of fuel supply for Winnipeg Transit since alcohol fuels can be obtained from renewable resources and production facilities for alcohol fuels have been built in Manitoba. With only partial substitution by alcohol fuels, diesel fuel requirements would still be substantial and transit operation would remain dependent upon the availability of diesel fuel.

In addition to the requirements for the development of a fuel mixture control system, this technology would require the use of two fuel tanks on board the vehicle and fuelling stations for both fuels. The fuelling systems for the alcohols would have to be designed to avoid the corrosive effect which alcohol fuels have on many standard fuel system components and materials.

It is estimated that the cost of alcohol fuels for a bulk purchaser such as Winnipeg Transit in the forecast year would be approximately $0.30 per unit of alcohol equivalent to a litre of gasoline (1981 dollars, see Appendix E) or about $0.33 per equivalent litre of diesel fuel if there were no Federal or Provincial taxes on fuel. Since a diesel/alcohol engine would operate at approximately the same efficiency as a diesel engine, the cost of fuel would drop to $.25 per km if 20% of the diesel fuel were replaced by alcohol. It was further estimated that the maintenance costs for this option would be $.25 per km, just marginally higher than the maintenance costs for the standard diesel bus, and that the capital cost would be $145,000. The estimate of the maintenance costs is based on the assumption that the power plant and fuelling system, which accounts for approximately 15% of the diesel bus maintenance costs, would be 20% - 25% more costly to maintain. The capital cost estimate was obtained from the Ontario Research Foundation, who are presently doing work with this fuel option.

**PROPANE**

During the 1950's and 1960's, the Chicago Transit Authority (CTA) operated an extensive fleet of propane powered buses. At the peak, CTA had over 2,600 propane buses. At the time, CTA used propane because of the low cost of the fuel relative to diesel. The engines used on the propane buses were modified gasoline engines with maintenance costs similar to comparable diesel engines. The overall engine life was similar to that of diesel engines as well, except that there were some problems with cracking of heads and burning of valves.

Since propane is a gas at normal temperatures and pressures and is usually stored in pressurized containers, fuelling operations can be more dangerous than with other fuels. During the period when CTA operated propane buses they had one major accident related to the use of propane.

More recently, European bus manufacturers have begun to produce propane powered vehicles. Both MAN in West Germany and Sauer in Switzerland have modified their regular diesel engines to operate with propane by adding a

spark ignition system and reducing the compression ratios. In North America, Ford and International Harvester are selling trucks with factory conversions of gasoline engines to propane.

Based on current European experience, bus engines converted to use propane operate with a thermo-dynamic efficiency approximately 10% lower than conventional diesel engines in buses. Since 1.65 litres of propane are required to yield the same heat energy as one litre of diesel, fuel costs for a propane bus would be cheaper than for a diesel bus only if propane were priced at less than 60% of diesel fuel.

One of the advantages of using propane as a fuel is that Canada presently has a surplus supply of propane. However, in the long run if a large number of fleets convert their automobiles, vans and small trucks to propane, this surplus could be substantially reduced. Propane, which is a component of both crude oil and natural gas, is not indigenous to Manitoba.

The safety of this option during operations and fuelling should be similar to the safety of diesel fuel if proper procedures and guidelines are followed.

It was estimated that the cost of propane would be $.27 per litre or approximately 60% of the expected cost of diesel; therefore, the fuel cost would be $.27 per vehicle kilometre as well. Relative to a diesel engine, a propane engine would save on oil requirements and would not have a fuel injection system to maintain. However, unlike the diesel engine the propane engine would have a spark ignition system which would require maintenance. Overall it is expected that the maintenance costs for a propane powered bus would be similar to the corresponding costs for a diesel powered bus.

Propane engines, which are often modified gasoline engines, could be up to $5,000 cheaper than diesel engines with the same power rating, based on estimates provided by Ford of Canada. Therefore, the capital cost of a propane powered vehicle was estimated to be $135,000 (1981 dollars).

## ALCOHOL

Considerable research is being performed on the use of alcohol fuels in both spark-ignited and self-ignited vehicle engines. In West Germany, MAN has tested a prototype transit vehicle powered by a modified version of one of their standard diesel engines. The engine combines the fuel injection system and high compression ratio associated with a diesel engine with a spark plug to ignite the charge. In tests performed using methanol, this option was found to improve thermal efficiency by 5% relative to a standard diesel engine used on a similar vehicle. Tests were also performed with ethanol and similar results were achieved. The engine design overcomes the cold starting problems often associated with alcohol fuels and permits cold starting at temperatures of -20° C.

Other researchers are developing self-igniting alcohol engines which either use the separate injection of a small proportion of diesel fuel to help ignite the main charge of alcohol fuel, or use alcohol fuels with ignition accelerators added. The thermal efficiencies of these options would be similar to the efficiency of a diesel engine since they would operate with similar compression ratios.

One of the major advantages of this option is that alcohol fuels are obtainable from renewable resources such as forest biomass or the cellulose fraction of municipal wastes. Manitoba has the potential of producing its own supply of alcohol fuels and work is already underway in that direction. Based on preliminary price estimates the minimum cost of producing a gasoline litre equivalent of alcohol fuel could be approximately $.30 (1981 dollars) in the future, as described in Appendix E. A number of factors could influence these costs; the different technologies that might be used are not all equally advanced in terms of technological development. This price, also does not include any Federal sales and excise taxes nor Provincial road taxes and, therefore, cannot be directly compared to the estimated price of diesel of $.45 per litre in the forecast year. However, since the diesel price would

include approximately $.11 per litre in sales, excise and road taxes, on an energy equivalent basis the alcohol fuels would still cost about 10% less even if similar taxes were imposed. Presently the Manitoba Government does not impose any road tax on the sale of alcohol fuels. It was assumed that this would also be the case in the forecast year and that only Federal taxes of 3¢ per litre would be added to the cost of alcohol fuels. Based on this price, the fuel costs for this option would be approximately $.21 per kilometre.

The maintenance costs of alcohol engines would be somewhat higher than comparable costs for diesel engines due to the addition of a spark-ignition system or a second fuel injection system. In addition, the corrosive nature of alcohol fuels may result in more frequent maintenance and replacement requirements for certain components of the engine. On the basis of these factors, it was assumed that a maintenance costs for this option would be $.26 per kilometre. It was further assumed that the capital cost of a standard transit vehicle equipped with an alcohol engine would be $145,000 (1981 dollars) based on conclusions drawn in a paper on alcohol-fueled buses by A. Neitz of MAN AG of West Germany.

## DIESEL/HYDRAULIC ACCUMULATOR

A prototype transit vehicle which utilizes hydraulic accumulators to recover the kinetic energy lost during braking has been built in West Germany by MAN. The bus was tested on a number of urban and suburban routes in West Berlin and achieved an average fuel saving of 23% on those routes. The bus was equipped with a diesel engine rated at approximately half the power of the engine normally used on the test vehicle. The choice of the diesel engine power for this option would be based primarily on the hill climbing requirements at a given speed.

The torque characteristics of this technology result in improved acceleration, and in turn higher average operating speeds. Under half-load conditions, the prototype vehicle operated with an average acceleration of 0.9

$m/sec^2$ in the speed range of 0-50 kilometres per hour. In contrast, a similar vehicle with a conventional diesel engine had an average acceleration of $0.7m/sec^2$ under the same conditions.

The design of a production vehicle which utilizes this technology would have to effectively integrate the hydraulic reservoirs with the structure of the vehicle. Specifically, the space requirements, extra weight and safety risks of the high pressure reservoirs would have to be considered. The reservoirs should be installed in the centre of the vehicle to reduce the weight on the rear wheels and to protect them in case of collision. The extra weight of the reservoirs could be substantially offset by reductions in the weight of the diesel engine and the size of the fuel tank required to provide the same range.

In Canada, the National Research Council has investigated the use of hydraulic accumulators in automobiles, and has performed research in the development of suitable hydrostatic transmissions. The NRC has concluded that the best opportunities for this technology lie in urban transit applications, but funding constraints have limited further research in this area at present.

The applications of this technology by Winnipeg Transit could reduce diesel fuel requirements by 20 - 25%, resulting in a fuel cost of $.21 per vehicle kilometre in the forecast year. The saving would be obtained at the cost of increased maintenance due to the complexity of the hydraulic transmission and energy storage systems. Increased maintenance requirements in this area would be partially offset by reductions in brake maintenance. It was assumed that maintenance costs would increase by 4¢ per kilometre due to the additional hydraulic system, and decrease by 1¢ per kilometre due to the reduced brake maintenance requirements. Therefore, maintenance costs would be $.27 per kilometre.

## exhibit 7.1

## Summary of Liquid Fuel Options

| OPTION | IMPORTANT CHARACTERISTICS | FUEL COST $/km | MAINTENANCE COSTS $/km | CAPITAL COST $ | ANNUALIZED* CAPITAL COST $/km | TOTAL COST $/km |
|---|---|---|---|---|---|---|
| Standard Diesel | - widely used<br>- proven reliability<br>- uncertain security of supply | .27 | .24 | 140,000 | .25 | .76 |
| Diesel/Alcohol | - up to 30% alcohol used in an emulsification with diesel<br>- only small proportion can be added when idling, therefore not very suitable for urban transit operations | .25 | .25 | 145,000 | .26 | .76 |
| Propane | - 10% loss in thermal efficiency<br>- lower cost than diesel on energy equivalent basis<br>- use of modified gasoline engine reduces capital cost<br>- increased security of fuel supply | .27 | .24 | 135,000 | .24 | .75 |
| Alcohol | - possible 5% gain in thermal efficiency<br>- due to corrosive nature may require new fuel supply system materials<br>- could be produced locally from forest biomass and/or municipal waste | .21 | .25 | 145,000 | .26 | .72 |
| Diesel/Hydraulic | - fuel savings of 20-25%<br>- improved acceleration<br>- weight of hydraulic partially offset by lighter engine<br>- increased maintenance and capital costs | .21 | .27 | 160,000 | .29 | .77 |

NOTES: * Based on real interest rate of 4% over economic life of 15 years and 50,000 km per vehicle per year.

As part of their evaluation of this technology, MAN estimated that a bus equipped with a hydraulic accumulator would cost 15% more than a comparable standard diesel bus. The capital cost of this technology was, therefore, assumed to be $160,000 (1981 dollars).

## SUMMARY

The important characteristics of each of the liquid fuel options and the fuel, maintenance and capital costs of these options are summarized in Exhibit 7.1.

It can be seen that in terms of cost, the only alternative to the diesel engine that shows a significant difference is the use of pure alcohol engines. The beneficial impact of this technology is based upon a fairly optimistic scenario concerning the future costs of the production of alcohol and on the assumption there will be no provincial or federal taxes imposed. If taxes similar to that paid for diesel fuel were imposed, the estimated operating costs would be very similar to that of diesel fuel.

These liquid fuel options are subjected to further evaluation in the next chapter, along with the electric traction options.

# 8. EVALUATION OF ALTERNATIVES

In this chapter the options to standard diesel bus technology described in the previous two chapters are evaluated. The first step in this process is to define the evaluation criteria to be used.

## EVALUATION CRITERIA

The evaluation criteria used are shown on Exhibit 8.1 together with the study team's rating of each option relative to the performance of the current diesel bus system. For the cost items, the differences are shown in dollars; positive implies a higher cost than the diesel bus, negative implies a cost saving relative to the diesel bus. For the other criteria, ratings were defined between +2 for very advantageous characteristics of a system to -2 for very disadvantageous characteristics when compared with a diesel bus system. A rating of 0 is neutral relative to the diesel bus system.

### Capital Costs

This refers to the capital costs of the vehicles, of increases in the infrastructure required, and of the electrical power supply system where applicable. The various liquid fuel option vehicles are all slightly more expensive than the standard diesel bus except for the propane vehicle which would be similar or slightly cheaper than the diesel bus. All would require some capital cost for the maintenance and fueling facilities required but this has not been included in the evaluation. The electric options are considerably more expensive in terms of capital cost than the standard diesel bus.

### Operating Costs

The operating costs of the various liquid fuel options are similar to those of a diesel bus except for alcohol where the lower projected price of alcohol in the future results in a decrease in operating costs. The electrical options are much cheaper in terms of fuel costs. In all cases future fuel prices have been used in this evaluation.

**Total Annual Costs**

The previous chapters have described the derivation of total annual costs. The propane bus has been estimated to have a lower total annual cost with future fuel prices. The other liquid fuel options are very similar in terms of total annual cost to that of a diesel bus. Of the electrical options, only the standard trolley coach has a positive rating in terms of total annual cost.

**State of Development**

All of the liquid fuel options require some further development before engines suitable for buses are produced commercially. They therefore have been given a score of -1 with respect to this criterion. The trolley coach is widely produced today and therefore it is neutral compared to the diesel bus. The trolley/diesel requires some work resulting in a score of -1. The trolley/flywheel requires a considerable amount of technological development and thus was given a score of -2.

**Technological Risk**

There are technological risks stemming from the additional work required to develop diesel/alcohol, alcohol and diesel/hydraulic accumulator buses. These risks have been assessed from Winnipeg Transit's point of view in making a commitment to purchase these vehicles. Therefore each of the liquid fuel options, with the exception of propane vehicles, has been given a -1. For the electrical options, the trolley coach and the trolley/diesel have been assigned a neutral score while the trolley/flywheel has been given a -2 score.

**Vulnerability to Petroleum Shortages**

There is potential for shortages of petroleum fuel in the future. Therefore, the vulnerability of the transit system to petroleum shortages, compared with the vulnerability of the diesel bus system, has been used as another criterion. The diesel/alcohol and diesel/hydraulic accumulators use

almost the same amount of diesel fuel as the pure diesel; therefore they have been given a neutral score with respect to this criterion. The propane and alcohol vehicles are superior to the diesel system and have been given a +1 score. The electrical options are relatively invulnerable to petroleum shortages; therefore they also have been given a score of +1.

**Maintenance and Servicing Convenience**

At the present time Winnipeg Transit uses basically one type of vehicle. This adds to the maintenance and servicing convenience; any vehicle can be maintained at any garage and many parts are interchangeable. When new systems are introduced there is some loss of flexibility. The diesel/alcohol, propane and alcohol buses and the trolley coach have been assigned a -1 with respect to this criterion. The diesel/hydraulic accumulator, trolley/diesel and trolley/flywheel vehicles have been given a -2 because these vehicles have two power plants, potentially causing additional problems and additional inflexibility in maintenance operations.

**Operating Flexibility**

This refers to the flexibility to move a vehicle from one route to another and to minimize deadheading in travel from garages to service. The various liquid fuel options are neutral compared to the standard diesel bus. The systems that require overhead wiring have been given a -1 rating in this category. The trolley/flywheel bus, because of its off-wire capability, has been given a neutral rating also.

**Flexibility to Changes in Travel Patterns**

The diesel bus fleet can be adjusted very quickly to respond to changes or unanticipated movements in the development of travel patterns. Systems based on liquid fuels similarly can adjust immediately. The options based on electrical supply are less flexible, although the trolley/flywheel is the most flexible of these.

**Passenger Service Implications**

As discussed in the previous chapters, the trolley coach system requires many passengers to change vehicles at transfer points. Therefore it has been given a -1 score. All other systems have been judged to be neutral with respect to this criterion.

**Noise Impacts**

The liquid fuel vehicles would have noise impacts similar to those of a diesel bus. The electric vehicles would be quieter on those sections of the route that they are operating electrically. The trolley coach system, however, would be serviced by diesel feeders mainly operating in residential areas and therefore has been given only a +1 rating. Similarly the trolley/diesel would be operating under diesel power in many residential areas and has been given a +1 rating. The trolley/flywheel vehicle would be operating under electrical power at all times and it has been given a +2.

**Visual Impacts**

This criterion is mainly concerned with the visual impact of the overhead line requirements. The liquid fuel options are rated as similar to the diesel bus as is the trolley/flywheel system which only has a small proportion of its route wired. The other two electrical options are given a negative score with respect to this criterion.

**Air Pollution Impacts**

The liquid fuel options would have similar air pollution impacts to those of a standard diesel bus system. The electrical options would have a positive impact.

## exhibit 8.1
## Evaluation of Technologies Relative to Standard Diesel Buses

| CRITERIA | POSSIBLE ALTERNATIVES TO STANDARD DIESEL BUS | | | | | | |
|---|---|---|---|---|---|---|---|
| | LIQUID FUEL OPTIONS | | | | ELECTRICAL OPTIONS | | |
| | DIESEL ALCOHOL | PROPANE | ALCOHOL | DIESEL/ HYDRAULIC ACCUMULATOR | TROLLEY COACH | TROLLEY/ DIESEL | TROLLEY/ FLYWHEEL |
| Differential Annual Costs Relative to Diesel Bus (Millions of $) | | | | | | | |
| Capital Cost | +$200,000 | -$200,000 | +$200,000 | +$800,000 | +$3,000,000 | +$3,300,000 | +$3,600,000 |
| Operating Cost | -$200,000 | - | -$1,400,000 | -$800,000 | -$3,300,000 | -$2,500,000 | -$3,100,000 |
| Total Costs | - | -$200,000 | -$1,200,000 | - | -$300,000 | +$800,000 | +$500,000 |
| Ratings Relative to Diesel Bus | | | | | | | |
| Total Cost | | | | | | | |
| Total Annual Costs | 0 | +1 | +2 | 0 | +1 | -1 | -1 |
| Technology | | | | | | | |
| State of Development | -1 | -1 | -1 | -1 | 0 | -1 | -2 |
| Technological Risk | -1 | 0 | 0 | -1 | 0 | -1 | -2 |
| Fuel Impact | | | | | | | |
| Vulnerability to Petroleum Shortages | 0 | +1 | +1 | .0 | +1 | +1 | +1 |
| Operational Considerations | | | | | | | |
| Maintenance and Servicing Convenience | -1 | -1 | -1 | -2 | -1 | -2 | -2 |
| Operating Flexibility | 0 | 0 | 0 | 0 | -1 | -1 | 0 |
| Flexibility to Changes in Travel Patterns | 0 | 0 | 0 | 0 | -1 | -1 | 0 |
| Passenger Service Implications | 0 | 0 | 0 | 0 | -1 | 0 | 0 |
| Environmental Considerations | | | | | | | |
| Noise Impacts | 0 | 0 | 0 | 0 | +1 | +1 | +2 |
| Visual Impacts | 0 | 0 | 0 | 0 | -1 | -1 | 0 |
| Air Pollution Impacts | 0 | 0 | 0 | 0 | +1 | +1 | +1 |
| Industrial Impacts | | | | | | | |
| Bus Industry Impacts | 0 | 0 | 0 | 0 | 0 | +1 | +1 |
| Other Industrial Impacts | +1 | 0 | +1 | 0 | +1 | +1 | +1 |
| Fiscal Impacts | | | | | | | |
| Impacts on Government Revenues | 0 | 0 | -1 | 0 | -1 | -1 | -1 |
| Canadian Balance of Payments | 0 | 0 | +1 | 0 | +1 | +1 | +1 |

**Bus Industry Impacts**

This criterion attempts to measure the potential impact on the Manitoba bus industry if a new technology is developed and applied in Winnipeg. For the various liquid fuel options it was judged that there would be relatively little impact because the engines would almost certainly be manufactured in other parts of North America. For the trolley/diesel and the trolley/flywheel systems, a positive rating was given; even if the motive power systems were manufactured elsewhere, experience would be gained in Manitoba in applying these.

**Other Industrial Impacts**

There may be other industrial impacts in applying the systems in Manitoba. Because of the potential impact on the alcohol production industry and consequent effects on agriculture, the diesel/alcohol and the alcohol vehicles have been given a positive ranking.

**Impact on Government Revenues**

Diesel fuel prices now include a considerable amount of taxes. These help support the road and other programs of the Provincial and Federal Governments. The alcohol and electrical energy charges do not include any such payments. Therefore, they must receive a negative ranking with respect to this criterion.

**Canadian Balance of Payments**

Canada is a net importer of petroleum and likely will be for at least the next decade. Therefore any system that reduces the amount of oil imports required should gain a positive rating. This is true for the alcohol and electrical options.

## EVALUATION

An initial evaluation of the alternatives in terms of the described criteria is presented in Exhibit 8.1. While relative weights have not been assigned to the various criteria, some conclusions can be drawn based on the information presented. The potential benefits of the various liquid fuel options, other than the alcohol powered bus, are quite minor when compared with the diesel bus; therefore, it appears that these should not be considered further as they do not have a reasonable cost advantage either. Of the electrical options only the trolley coach has a beneficial cost position (on the basis of future fuel costs). The other benefits and disbenefits for all the electrical options more or less balance out.

## CONCLUSIONS

Based on the previous analysis, the two systems which might be advantageous when compared with standard diesel buses are:

- alcohol fueled buses;
- trolley coaches.

When examining the total costs it should be noted that none of the options have a lower total annual cost than the diesel system under existing fuel prices. The alcohol fueled bus and trolley coach options have lower total annual costs with a projected 35% increase in petroleum fuels, based on the estimates of future alcohol prices and the assumption that electricity prices will not increase in real terms. The future prices for alcohol and electricity also do not include any allowance for taxation. When these are included the total price becomes similar to that of a diesel bus system.

What then are the implications for Winnipeg? It could be argued from the above discussion that, because increases in fuel prices are required before making any of the options economic, Winnipeg should defer any decision

for several years to see if fuel prices do increase in real terms. Alternatively, it could be argued that Winnipeg should anticipate the increases in fuel prices and start to develop its system based on alternative fuels.

It is our opinion that diesel fuel price increases of the magnitude needed to make trolley coach operation economically viable are quite likely and that Winnipeg should commit itself to the development of a trolley coach system. The amounts needed would be included in capital budgets and physical planning should begin. However, the point where such a system becomes economically viable is still several years off and irrevocable steps such as purchase of vehicles should not be taken until passenger ridership and fuel price breaks are more strongly established. It should also be noted that the costing of the trolley system was based on a relatively large network with 416 vehicles required for peak hour service in 1999. It is probable that a sub-set of this network could be economic within a shorter time scale. The next chapter discusses these possibilities.

Alcohol fueled vehicles also appear attractive given expected diesel fuel price increases. However implementation could not begin immediately as no suitable engine is produced in North America today although one could be developed with relatively little work by the major manufacturers. The first step would be to determine if arrangements could be made to produce such engines. As discussed previously and in more detail in Appendix E, the economics of production of ethanol are hypothetical at the present time although they appear promising. The use of alcohol fueled buses does not conflict with the implementation of a trolley coach system as the trolley coaches are proposed for high density routes only. A program of alcohol fueled buses on light density routes combined with a core of trolley coach routes is quite possible. However, because of the potential uncertainties with both the production and use of alcohol fuels, we cannot recommend their implementation at the present time.

## 9. INITIAL SYSTEM

Based on the analysis of costs for diesel transit service and for the electric traction options, it was concluded that the standard trolley technology could be cost-effective for certain routes in Winnipeg given the 1999 expected levels of passenger demand and a 36% increase in the real cost of diesel fuel. Other electric traction options such as the trolley/diesel and trolley/flywheel were more costly than the diesel and standard trolley coach and they also involved a higher degree of risk given the developmental nature of the technology. The estimated annual savings in 1999 of trolley coach service when compared to conventional diesel buses amounted to approximately $700,000 (1981 dollars) when applied to nine major routes in Winnipeg. These savings were gained because of the relatively high service frequency on the nine routes selected; the more heavily serviced routes are more advantageous for electrical operation because the direct cost savings of converting to electricity more than off-set the added infrastructure costs for overhead cabling, sub-station, etc.

This chapter describes when and under what conditions an initial trolley coach service would be appropriate and provides an outline for subsequent expansion of the system.

### NETWORK IDENTIFICATION

As has been discussed, the suitability of trolley service is a function of service frequency which in turn relates to passenger demand and the differential cost between diesel fuel and electricity. An important consideration in the implementation of a Stage 1 trolley service is that of the minimum adequate size of the system to justify the additional costs of trolley coach related services (eg. power supply and emergency vehicle, maintenance crews, vehicle maintenance equipment, parts, etc.). From available documentation, it was indicated that the usual minimum size for a trolley system is 75 vehicles.

The first step in developing an implementation plan was to determine the 1987 service characteristics for the nine major routes selected in the 1999 system. 1987 was considered an appropriate time frame because it would allow for the necessary decision making process to take place and construction to be undertaken as well as allow for differential price increases for electricity and diesel to occur. The 1987 passenger demands were estimated by interpolating between the existing service characteristics on these routes and the expected service characteristics in 1999 as indicated by the 1999 estimated demand. The critical 1987 characteristics of the nine routes are summarized in Exhibit 9.1. The heavier routes, as reflected by the number of vehicles, are Academy/Stafford/McGregor, Corydon/North Main, St. Mary's/Ellice, Osborne/Selkirk, Portage/East Kildonan and Pembina/Kings Park/Southwest Corridor. Based on the information in Exhibit 9.1, particularly the density of traffic on each route, and after discussions with Winnipeg Transit staff, it was concluded that the four most promising routes are Corydon/North Main, Osborne/Selkirk, East Kildonan/Polo Park and Pembina/Kings Park.

Only the East Kildonan service on the Portage route was considered to be appropriate for more detailed analysis because of the nature of service on the Portage routes (i.e. the mix of local and express service and the exclusive bus lane which is proposed as part of the transportation plan). The express routes on Portage were not considered as candidates for electrification in 1987.

Based on the four preferred routes for 1987, four Stage 1 service alternatives were developed:

- Alternative 1 - Corydon/North Main - East Kildonan/Polo Park - Osborne/Selkirk;
- Alternative 2 - Corydon/North Main - East Kildonan/Polo Park;
- Alternative 3 - Corydon/North Main - Pembina;
- Alternative 4 - Pembina - East Kildonan/Polo Park.

## exhibit 9.1

## Potential Trolley Coach Routes - 1987 Characteristics

| ROUTE | NO. OF VEHICLES REQUIRED | GARAGE | AVERAGE VEH-KM PER VEHICLE PER DAY | PEAK HEADWAY (MIN.) | ROUND TRIP ROUTE DISTANCE (KM) | AVERAGE SPEED INCLUDING LAYOVER (KM/HR) | PEAK PASSENGER VOLUME (PASS./HR.) | PEAK HOUR LOADING (PASS/VEH) | VEH-KM PER WEEKDAY |
|---|---|---|---|---|---|---|---|---|---|
| Academy/Stafford/ McGregor | 30 | 17 FRG 13 NG | 156.9 | 4.3 | 31.1-31.5 | 14.8 | 860 | 60.3 | 4723 |
| Corydon/North Main | 49 | 29 FRG 20 NG | 158.3 | 2.6 | 31.2-34.8 | 15.8 | 1220 | 53.1 | 7300 |
| St. Mary's/Ellice | 33 | 22 FRG 11 SJG | 146.8 | 3.7 | 35.2-36.5 | 17.9 | 934 | 57.1 | 4844 |
| Mountain/Sargent | 20 | 11 FRG 9 SJG | 171.4 | 7.7 | 30.9-28.0 | 12.1 | 421 | 54.0 | 3428 |
| Osborne/Selkirk | 31 | 17 FRG 14 SJG | 145.3 | 5.0 | 30.7-33.6 | 12.4 | 674 | 56.4 | 4506 |
| Notre Dame/Logan | 17 | 17 FRG | 102.2 | 3.4 | 11.6-13.8 | 14.5 | 1040 | 58.1 | 1738 |
| Portage (Polo Park)/ East Kildonan | 44 | 26 FRG 18 NG | 191.8 | 2.2 | 23.8-31.5 | 17.1* | 1125 | 55.8 | 7738 |
| Pembina/King's Pk/ Southwest Corridor | 32 | 32 FRG | 323.0 | 2.6 | 27.0-34.8 | 32.5-29.5* | 1730 | 56.4 | 9784 |
| Transcona/East Corridor | 6 | 6 FRG | 212.4 | 12.9 | 27.4-29.1 | 16.6 * | 459 | 62.1 | 1274 |

NOTES: FRG - Fort Rouge Garage
NG - North Garage
SJG - St. James Garage
* - Includes part of route on Transit Priority corridor

Exhibit 9.2 through 9.5 illustrate the location and corridors serviced by each of these alternatives.

Based on interpolating the EMME OUTPUT (a.m. peak work trips) the estimated 1987 ridership and per cent increase over existing ridership are, for each alternative:

| | Existing Ridership | 1987 Estimated Ridership | Percent Increase |
|---|---|---|---|
| Alternative 1 | 2580 | 3020 | 17.1% |
| Alternative 2 | 1930 | 2350 | 21.8% |
| Alternative 3 | 2520 | 2950 | 17.1% |
| Alternative 4 | 2340 | 2850 | 22.0% |

It is important to note that these growth rates (2.7% - 3.3% per annum) are considerably higher than that which Winnipeg Transit has achieved in the past few years and is more than the overall growth rate of the entire system as projected in long range transportation plans.

Exhibit 9.6 provides a summary of the major operating characteristics of each alternative. As would be expected the most costly ($15 million) alternative to construct is Alternative 1 because it also has the longest two-way route distance (25 km). This information and the operating characteristics were used to estimate capital and operating costs.

**COSTING**

The first step in this process was to examine the selected routes in more detail. The number of vehicles required for each route was examined as well as the kilometres of service during each part of the day based on 1981 service characteristics and expected 1987 characteristics. Cost estimates

**exhibit 9.2**

**Proposed Network for Initial Trolley Fleet - Alternative 1**

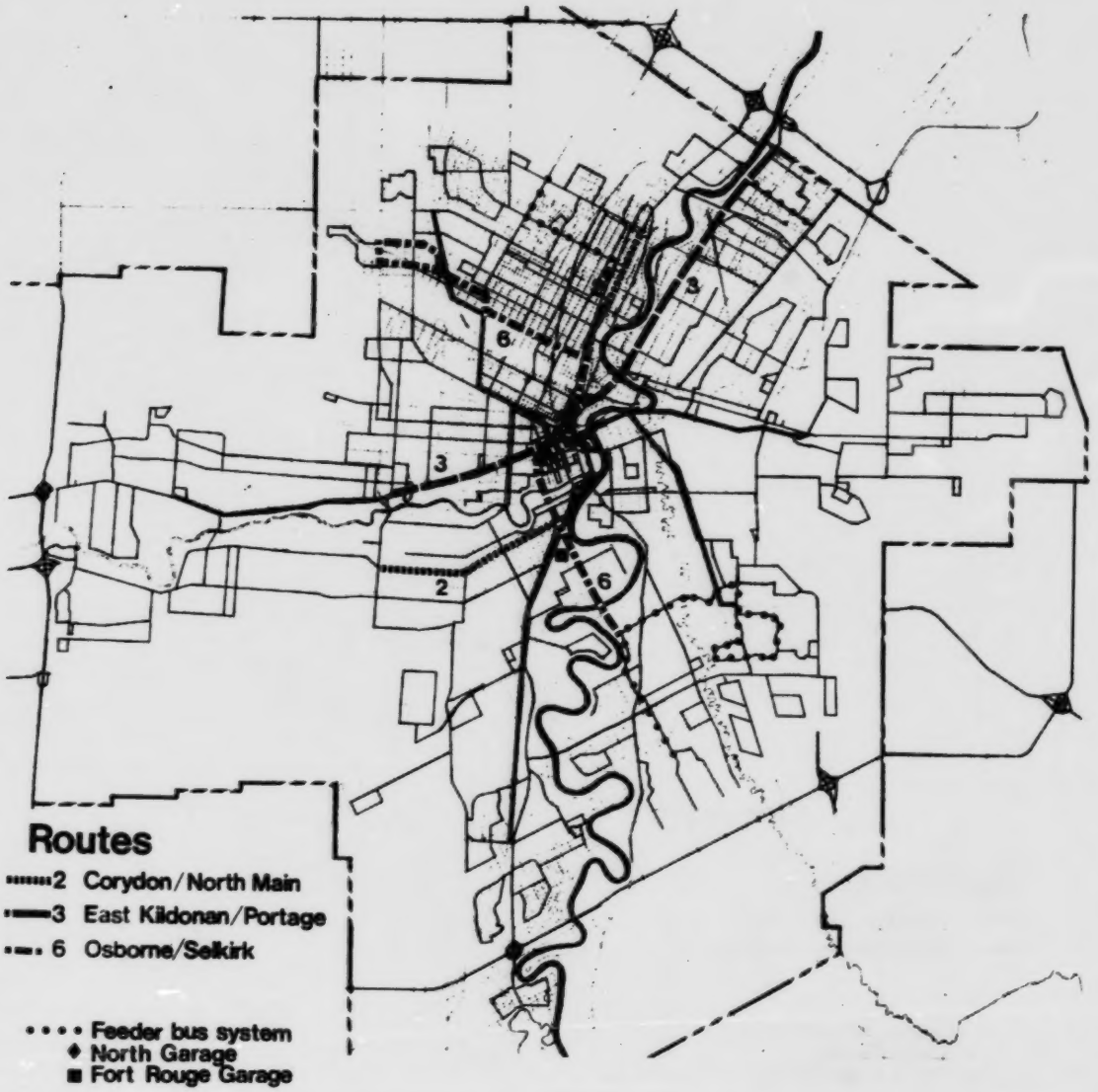


**exhibit 9.3**

**Proposed Network for Initial Trolley Fleet - Alternative 2**

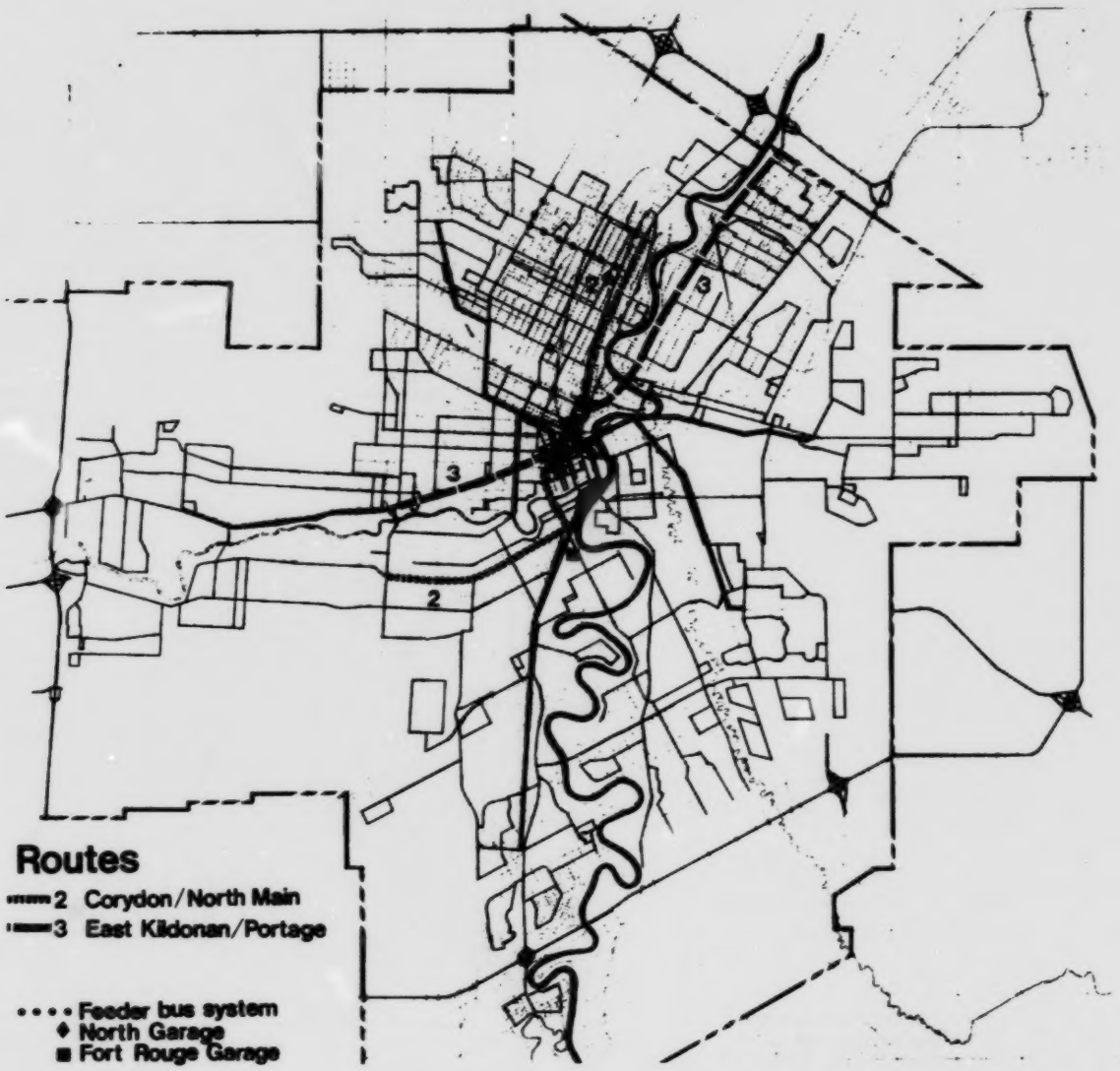


**exhibit 9.4**

**Proposed Network for Initial Trolley Fleet - Alternative 3**

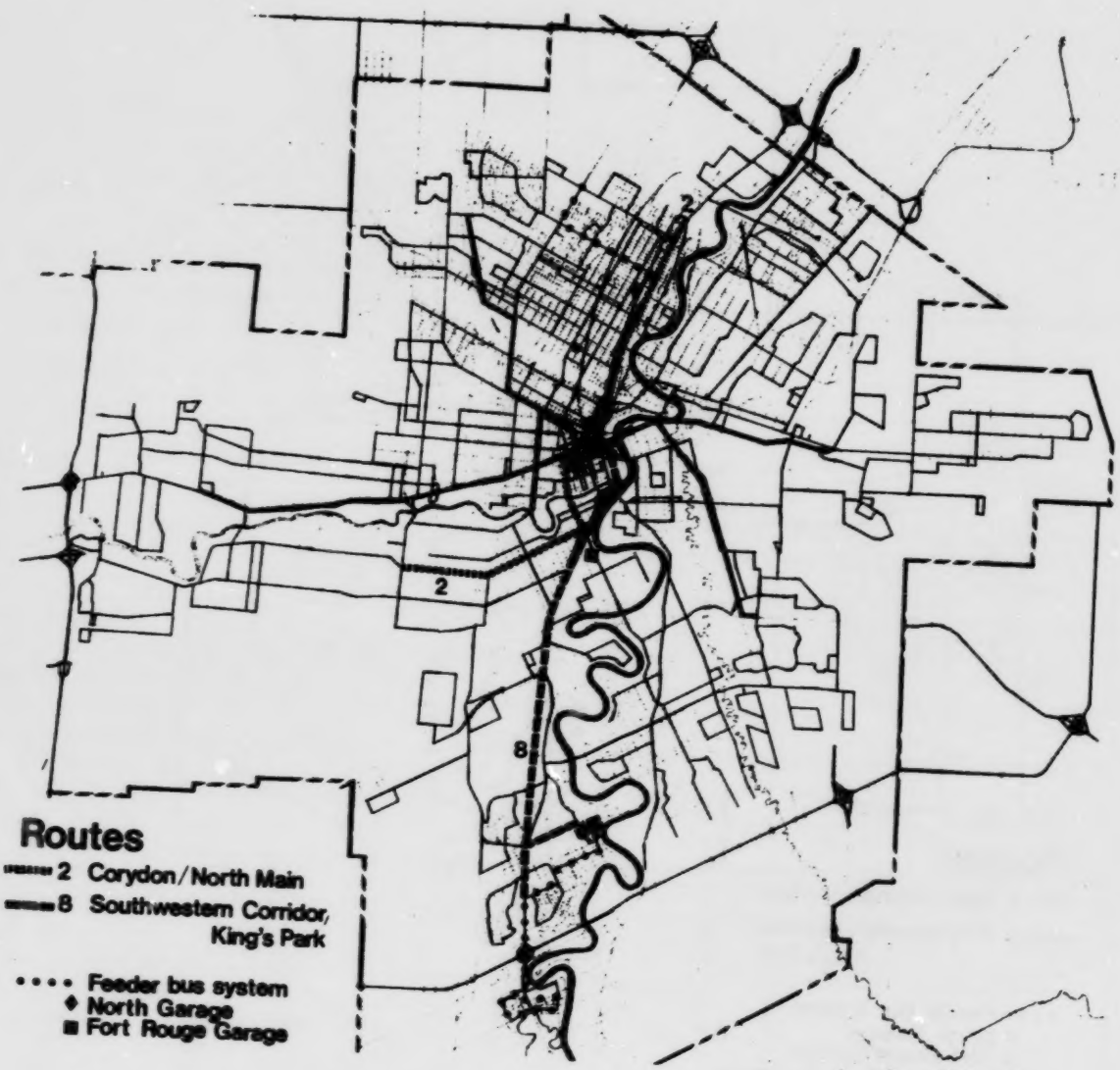


**exhibit 9.5**

**Proposed Network for Initial Trolley Fleet - Alternative 4**

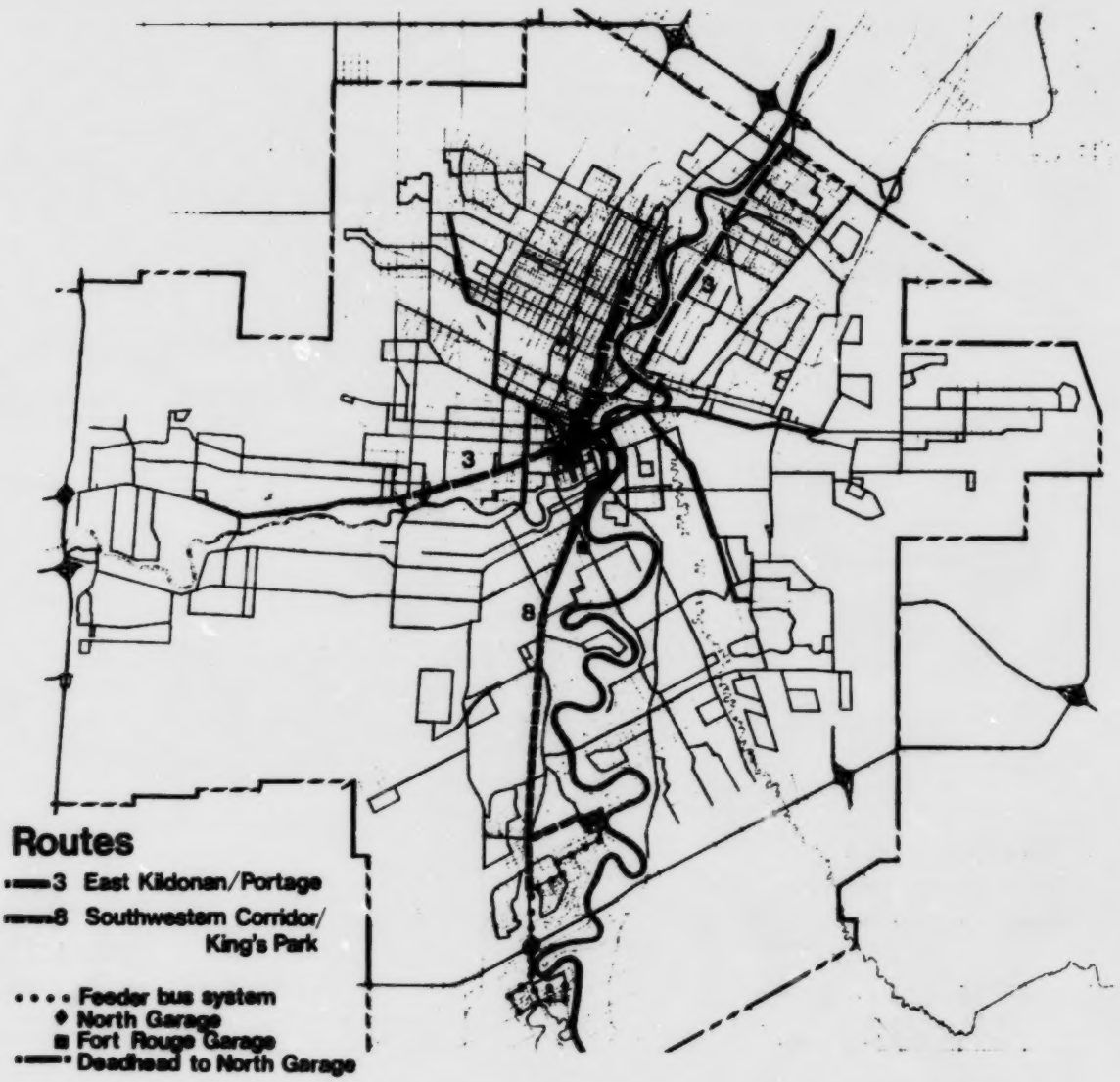


**exhibit 9.6**

**Summary of Characteristics of Alternatives**

| | TWO WAY ROUTE DISTANCE (KM) | VEH-KM PER WEEKDAY (KM) | DEADHEADING VEHICLE-KM (KM) | INFRASTRUCTURE CAPITAL COSTS ($,000 In 1981 Dollars) |
|---|---|---|---|---|
| ALTERNATIVE 1: East Kildonan/Portage (Polo Park), N. Main/Corydon, Osborne/Selkirk | 25.0 | 20,330 | 1,455 | 15,042 |
| ALTERNATIVE 2: East Kildonan/Portage (Polo Park) N. Main/Corydon | 17.1 | 16,200 | 1,158 | 10,700 |
| ALTERNATIVE 3: Southwest Corridor, N. Main/ Corydon | 19.0 | 18,090 | 1,010 | 12,272 |
| ALTERNATIVE 4: Southwest Corridor, East Kildonan/Portage | 21.2 | 18,780 | 1,252 | 13,841 |

## exhibit 9.7

## Estimated Annual Costs of Alternatives in 1981 Dollars with 1987 Ridership Demand

| | VEHICLES NEEDED | AMORTIZATION OF CAPITAL | | VEHICLE MAINTENANCE ($000) | ELECTRICAL SYSTEM MAINTENANCE ($000) | MOTIVE POWER ENERGY PURCHASE ($000) | TOTAL ($000) |
|---|---|---|---|---|---|---|---|
| | | INFRASTRUCTURE ($000) | VEHICLES ($000) | | | | |
| ALTERNATIVE 1 | | | | | | | |
| - Trolley Coach | 120 | 963 | 1536 | 1172 | 289 | 285 | 4245 |
| - Diesel with current prices | 120 | - | 1510 | 1449 | - | 1091 | 4050 |
| - Diesel with 1987 prices | 120 | - | 1510 | 1449 | - | 1389 | 4348 |
| ALTERNATIVE 2 | | | | | | | |
| - Trolley Coach | 92 | 685 | 1178 | 933 | 289 | 230 | 3315 |
| - Diesel with current prices | 92 | - | 1158 | 1149 | - | 869 | 3176 |
| - Diesel with 1987 prices | 92 | - | 1158 | 1149 | - | 1106 | 3413 |
| ALTERNATIVE 3 | | | | | | | |
| - Trolley Coach | 81 | 785 | 1037 | 1043 | 289 | 253 | 3407 |
| - Diesel with current prices | 81 | - | 1019 | 1283 | - | 971 | 3293 |
| - Diesel with 1987 prices | 81 | - | 1019 | 1283 | - | 1236 | 3538 |
| ALTERNATIVE 4 | | | | | | | |
| - Trolley Coach | 76 | 886 | 973 | 1082 | 289 | 259 | 3489 |
| - Diesel with current prices | 76 | - | 957 | 1332 | - | 1007 | 3296 |
| - Diesel with 1987 prices | 76 | - | 957 | 1332 | - | 1282 | 3571 |

were developed for each of the four alternatives based on the estimated 1987 service requirements and 1987 fuel costs. 1987 diesel fuel costs were estimated at 42¢ per litre, expressed in 1981 dollars. As described in previous chapters, electrical costs were assumed to remain constant. The results of this analysis are summarized in Exhibit 9.7. From the exhibit it is evident that all of the alternatives would have an adequate fleet size for a trolley coach service, with the largest number of vehicles (120) being required for Alternative 1 and the smallest number (76) for Alternative 2. Taking into account all costs, it is estimated that all of the alternatives would be cost-effective when 1987 fuel prices are used but not when current fuel prices are included; the exhibit indicates that the standard trolley alternatives are 2.3% to 3.7% less expensive than the diesel service. (It should be pointed out that the trolley coach options are 4% to 5% less expensive for the 1987 service based on a 35% real increase in the cost of diesel fuel - the estimated 1990 real increase in fuel costs).

It should be pointed out that in developing the annual costs the electrical system maintenance costs are the same for all alternatives because each requires the base maintenance requirements in terms of crews, trucks, etc. The relatively small differences in the scale of operations do not have an impact on the costs of power supply system maintenance.

Because the alternatives analyzed have only marginal differences in terms of potential cost savings, the identification of the more appropriate routes is a function of other criteria. In this regard, the estimated benefits of the Pembina route are based on an exclusive busway which may not be implemented by 1987. It would be appropriate therefore to exclude Pembina from Stage 1 of a trolley coach service unless the busway implementation would coincide with a Stage 1 trolley system.

Because of the high expected ridership increase inherent in the 1987 system, a cost analysis of the existing demand and therefore existing service was undertaken to assess the sensitivity of costs to ridership and growth in ridership. Exhibit 9.8 summarizes the cost analysis indicating that none of

## exhibit 9.8

## Estimated Annual Costs of Alternatives in 1981 Dollars with 1981 Ridership Demand

| | VEHICLES NEEDED | AMORTIZATION OF CAPITAL | | VEHICLE MAINTENANCE ($000) | ELECTRICAL SYSTEM MAINTENANCE ($000) | MOTIVE POWER ENERGY PURCHASE ($000) | TOTAL ($000) |
|---|---|---|---|---|---|---|---|
| | | INFRASTRUCTURE ($000) | VEHICLES ($000) | | | | |
| ALTERNATIVE 1 | | | | | | | |
| - Trolley Coach | | 963 | 1190 | 881 | 289 | 220 | 3543 |
| - Diesel with current prices | 93 | - | 1171 | 1112 | - | 841 | 3124 |
| - Diesel with 1987 prices | 93 | - | 1171 | 1112 | - | 1070 | 3353 |
| ALTERNATIVE 2 | | | | | | | |
| - Trolley Coach | 71 | 685 | 908 | 698 | 289 | 177 | 2757 |
| - Diesel with current prices | 71 | - | 894 | 882 | - | 667 | 2443 |
| - Diesel with 1987 prices | 71 | - | 894 | 882 | - | 849 | 2625 |
| ALTERNATIVE 3 | | | | | | | |
| - Trolley Coach | 54 | 785 | 691 | 763 | 289 | 180 | 2708 |
| - Diesel with current prices | 54 | - | 680 | 964 | - | 729 | 2373 |
| - Diesel with 1987 prices | 54 | - | 680 | 964 | - | 928 | 2574 |
| ALTERNATIVE 4 | | | | | | | |
| - Trolley Coach | 64 | 886 | 819 | 9108 | 289 | 214 | 3116 |
| - Diesel with current prices | 64 | - | 806 | 1147 | - | 868 | 2821 |
| - Diesel with 1987 prices | 64 | - | 806 | 1147 | - | 1105 | 3058 |

the alternative trolley coach systems is cost-effective for 1981 ridership levels; the trolley coach systems would cost between 2 and 5% more than the diesel service based on the etimated 1987 fuel costs for diesel. If the "future" fuel costs (i.e. 45¢/litre for diesel fuel) were applied, the only alternative that would be cost-effective would be Alternative 4, where the trolley system would cost marginally less (i.e. approximately .5%) than the diesel service. If, however, none of the alternatives with the Southwest Corridor routes can be implemented until the busway is completed, the next most attractive would be Alternative 2 which includes the Corydon and East Kildonan service. Moreover, Alternative 4 does not have sufficient vehicles to satisfy the minimum size requirements for a trolley service (i.e. 75 vehicles).

It can be seen from this analysis that two things must happen before the use of trolley coaches on these alternative route systems is economic:

- ridership must grow substantially beyond the 1981 volumes towards the 1987 expected figures;
- the price of diesel fuel must increase towards the 42¢ per litre (in 1981 dollars) figure predicted.

## Selection of Alternatives

Based on the foregoing discussion, we do not foresee the inclusion of the Southwest Corridor in the initial system because:

- the timing of the construction of the various segments of the busway is in doubt. It would not make sense to build the overhead required until the entire busway is in operation;
- the cost-effectiveness of the Southwest Corridor is very similar to that of the other corridors without taking into account the lower useage that this corridor might have during the summer months when the university is not operating at full capacity;
- the Southwest Corridor does not share overhead wire with other routes; it can be added to the trolley coach system when the busway is completed.

Therefore the choice is between Alternatives 1 and 2. These are identical except that Alternative 1 includes the Osborne/Selkirk route. The two systems are very similar in terms of cost-effectiveness relative to the diesel bus system. We would therefore recommended that Alternative 1 be selected as some economies of scale are possible with the larger system and because larger volumes of diesel fuel would be saved with this system.

It must be emphasized, however, that this selection is based on the assumption that the expected ridership growth to 1987 will take place as well as the expected real increase in fuel prices.

## SENSITIVITY ANALYSIS

The feasibility of converting from standard diesel buses to standard trolley buses is a function of two major factors:

- the cost differential between diesel fuel and electrical power;
- the frequency of service on the selected routes which is based upon passenger demand. As has been illustrated in the analysis, the more frequent the service the better suited the route or service is to electrification because the fixed costs associated with overhead wire, substations, etc. is being defrayed over more service.

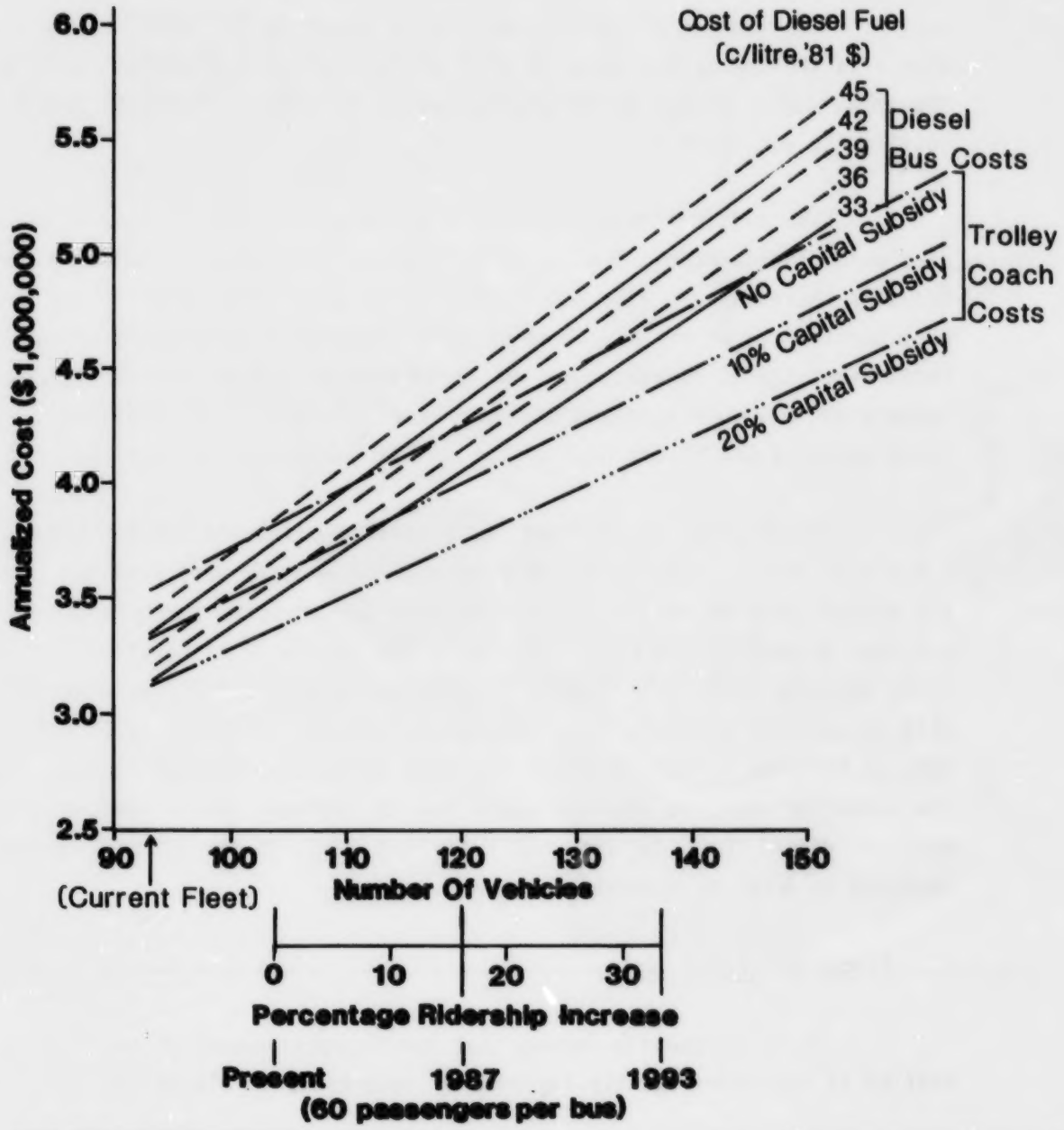
A third variable which can affect the suitability of converting to trolley service is that of special government capital subsidies. If, for example, a senior level of government felt it desirable to have certain transit services electrified, it might be appropriate for that level of government to provide special capital subsidies for conversion. Such subsidies are available in Ontario. The Federal Government has also provided capital subsidies for conversion of automobiles to alternate fuels and might be persuaded to provide subsidies for conversion of transit vehicles.

### Sensitivity to Fuel Prices and Subsidy Levels

Exhibit 9.9 provides a graphic representation of the interaction between these three important variables for the recommended transit alterna-

**exhibit 9.9**

**Relative Annual Cost For Diesel Bus And Trolley Coach In 1981 Dollars**



tive. This exhibit reflects total annual costs for Alternative 1 for a diesel operation under five cost estimates for diesel fuel and for different operating levels (number of buses). In addition, the exhibit also illustrates the annual costs of a trolley bus operation for the recommended alternative under three capital subsidy alternatives: 0% capital subsidy, a 10% subsidy, and a 20% capital subsidy.

Exhibit 9.10 provides an example of how Exhibit 9.9 should be interpreted. The example indicates that for a fleet of 110 vehicles the annual cost of a trolley system would be $3.5 million with a 20% capital subsidy and the annual cost of the deisel service would be $4.1 million with diesel fuel costing 45¢ per litre.

The critical determinant of trolley suitability is number of vehicles which indicates the density of service over the proposed network. Recent industry increases are also illustrated based on a load factor of 60 passengers per vehicle at the peak load point as opposed to the present average load factor (actual) of 66 passengers on these routes. Thus, although the actual numbers of vehicles assigned today to the 3 routes of Alternative 1 is 93 there would be 103 if the load factor were 60 passengers per vehicle.

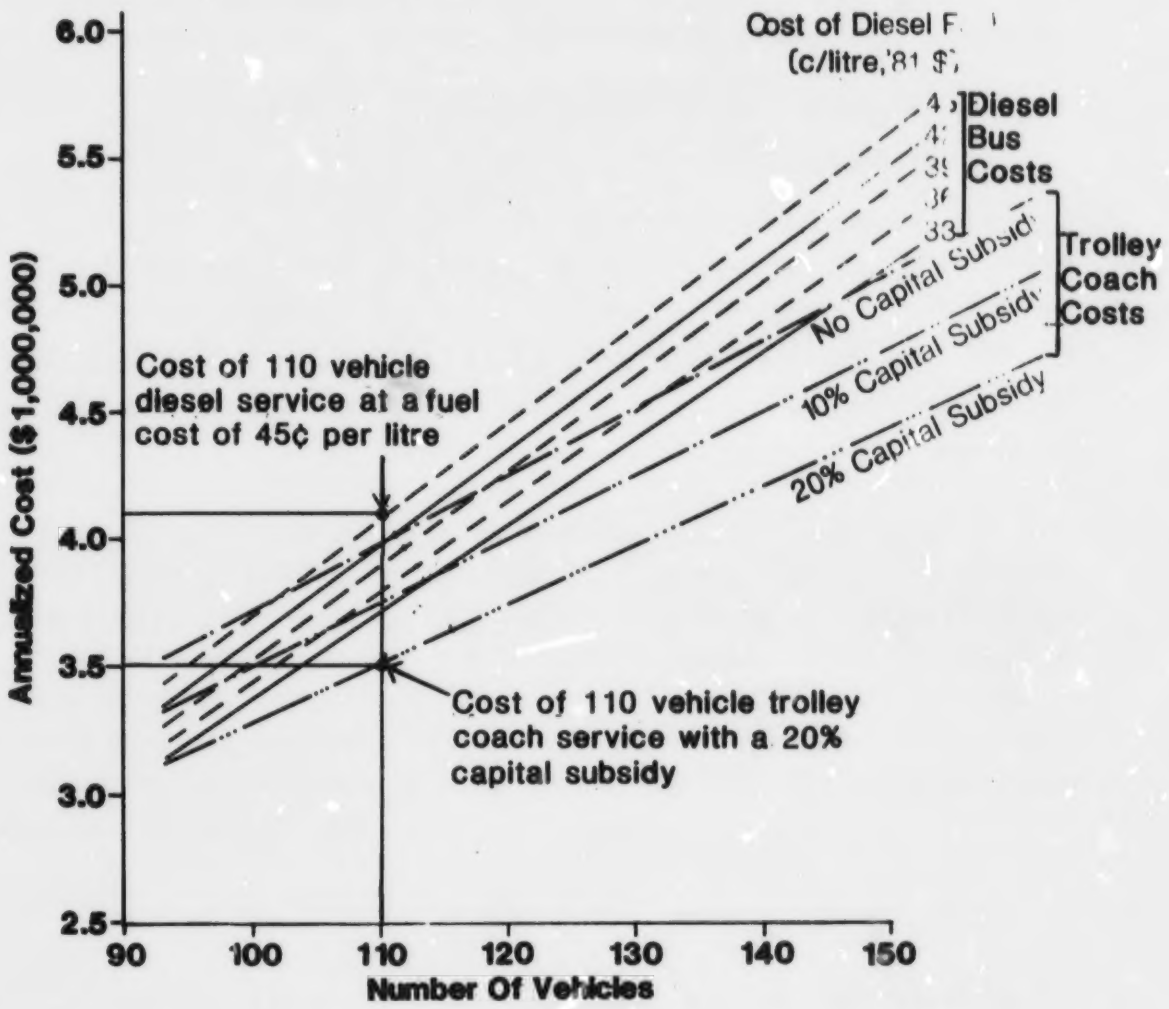
As is shown on the Exhibit, a trolley bus operation for Alternative 1 would be cost effective now, if a 20% capital subsidy were provided. With a 10% capital subsidy and no increase in fuel cost, service needs would have to increase to approximately 115 vehicles on the routes of Alternative 1 (from 93 - 103 vehicles today) for trolley service to be cost effective; alternatively with no service increase the price of diesel fuel to Winnipeg Transit would have to increase to 42¢ per litre (in 1981 dollars). With no capital subsidy the number of vehicles required would have to increase to 120 vehicles and the cost of diesel fuel to 39¢ per litre (in 1981 dollars); both these are expected to occur by approximately 1987.

Electrical Power Costs

It is worthwhile noting that the attractiveness of the trolley operation is not significantly improved by reductions in electrical power costs

**exhibit 9.10**

**Example Application of Relative Annual Cost for Diesel Bus and Trolley Coach in 1981 Dollars**



because electricity costs only account for 6% of the total annual costs of a trolley bus system. For example, a 40% reduction in electricity costs would only reduce the overall costs by 2.7%; not enough to make a trolley system financially advantageous for the existing service (Alternative 1).

**SUBSEQUENT ADDITIONS TO THE SYSTEM**

Subsequent routes which might be added to the trolley coach system, in order of our ranking of their relative priority, are as follows:

- Southwest Corridor (when the busway is completed);
- St. Mary's/Ellice;
- Academy/Stafford/McGregor;
- Mountain/Sargent.

The Portage routes which operate as express routes also might be considered once the exclusive bus lane design for the Portage Service is finalized.

The above ranking is based on expected 1987 ridership. Because these projections may vary by route over time it would be necessary to undertake route specific assessments of the costs and benefits as ridership levels change.

## 10. CONCLUSIONS AND RECOMMENDATIONS

In this report a large number of alternatives to conventional diesel bus services were identified. These technologies were put through a number of screenings in terms of:

- the state of technological development;
- generalized costing at the various levels of capacity and a comparison of these with expected demands in Winnipeg;
- for selected options, a more detailed examination of their expected costs and other implications. This resulted in a selection of trolley coach and alcohol fueled buses as having potential application to Winnipeg.

Before alcohol fueled buses can be introduced, an alcohol engine suitable for bus operations has to be developed. Some efforts in this direction are currently going on in Europe but not yet in North America. Also the technology and availability of alcohol fuels at an acceptable price has yet to be established.

Various initial trolley bus systems were examined; the initial system selected for implementation was made up of the Osborne/Selkirk, Corydon/North Main and East Kildonan/Portage (Polo Park) routes. The Southwest Corridor should also be considered if the busway is constructed in its entirety. This system will be economically viable only if the anticipated increases in the price of diesel fuel and expected levels of ridership occur and/or a capital subsidy is made available to cover part of the cost of the overhead power distribution system.

Based on the foregoing we make the following recommendations:

1. **WINNIPEG SHOULD ADOPT AS A CONDITIONAL GOAL THE IMPLEMENTATION OF A TROLLEY COACH SYSTEM.** This should be on the basis of the initial system developed in the study (Osborne/Selkirk, Corydon/North Main, and East Kildonan/Portage (Polo Park) routes, and perhaps also including the Southwest Transit Corridor routes), recognizing that the designation of routes may change if growth patterns are different than presently expected. As previously described the trolley coach system would be cost-effective under various circumstances such as:

- o with a 20% capital subsidy and current ridership levels and fuel costs;

- o with a 10% capital subsidy and either an increase in the number of vehicles required to serve these routes to 115 vehicles (representing a 12% increase in ridership) or a diesel fuel price increase to between 39¢ and 42¢ per litre with the present level of patronage and of service;

- o with no capital subsidy but with a fuel price increase to 39¢ per litre and a growth in ridership that would require 120 vehicles in service on these routes;

2. **THE NECESSARY CAPITAL FUNDING FOR THE PROJECT SHOULD BE INCLUDED IN THE CITY'S FIVE YEAR CAPITAL PROGRAM.** The estimated cost of implementation is $40 million. [This includes $25 million for vehicles and $15 million for fixed installations, expressed in 1981 dollars]. Construction is presently projected to begin in 1985 with completion in 1987. The vehicle capital costs would be offset by approximately $17 million in diesel vehicle purchases which would not be necessary if trolley coaches are purchased. Because of the difference in the expected economic lives of the two types of vehicles the effective annual costs of the two types would be very similar. If capital assistance were provided, the effective annual costs of the trolley coaches would be less than that for diesel buses.

3. **POTENTIAL SOURCES OF CAPITAL SUBSIDY SHOULD BE EXPLORED.** These might include the Provincial Government which is interested in the development of the hydro-electric resources of northern Manitoba and the federal government which has set a precedent in providing capital subsidies for the conversion of automobiles to alternative sources of fuel.

4. **THE GROWTH IN TRANSIT RIDERSHIP AND FUEL PRICES SHOULD BE MONITORED** closely to determine when these systems become cost-effective. Developments may advance or retard the time when the introduction of trolley coach service is economic.

5. **PHYSICAL PLANNING SHOULD BEGIN** in terms of electricity supply and other needs to ensure that the implementation of the system will be made as easy and as inexpensive as possible. Items that could be considered would be the reservation of sites for substations, the possible adoption of lamp standards and utility poles suitable for future installation of trolley coach overheads and other functions of the City and Winnipeg Hydro.

6. **DISCUSSIONS SHOULD BEGIN ON THE APPROACH TO BE TAKEN WITH RESPECT TO ELECTRICAL POWER PRICING AND THE CONSTRUCTION AND MAINTENANCE OF THE ELECTRICAL SYSTEMS.** Both Winnipeg Hydro and Manitoba Hydro should be contacted to discuss electrical pricing. For example, it may be possible that Manitoba Hydro would wish to develop a base load for its new hydro-electric projects and would consider providing electrical power to Winnipeg

Transit under a different rate structure than that currently used for industrial users.

7. **DISCUSSIONS SHOULD BEGIN WITH ENGINE MANUFACTURERS** to explore the possibility of producing an alcohol fueled bus engine. The economics of the production of the alcohol fuel should be investigated in more detail, particularly its production from municipal wastes. It might be more appropriate for the Provincial or Federal Governments to undertake these investigations than for Winnipeg Transit to take the lead.

8. **WINNIPEG TRANSIT SHOULD MONITOR DEVELOPMENTS IN TRANSIT TECHNOLOGY** over the coming years. This would include progress with vehicles such as the trolley/flywheel, the trolley/diesel, buses fueled with compressed natural gas, and the diesel or alcohol fueled vehicle with on-board energy storage through hydraulic accumulators, batteries or flywheels.

9. **WINNIPEG TRANSIT AND OTHER DEPARTMENTS OF THE CITY OF WINNIPEG SHOULD DEVELOP A PROCESS TO MAKE THE CRITICAL DECISIONS ON THE IMPLEMENTATION OF THE PROPOSED TROLLEY COACH SYSTEM.** The process includes the monitoring of developments as described above and the establishment of a mechanism to make the necessary decisions in a timely manner.

# APPENDIX A

## DESCRIPTION OF ALTERNATIVE TECHNOLOGIES

## DESCRIPTION OF ALTERNATIVE TECHNOLOGIES

### STANDARD URBAN TRANSIT BUS

The vast majority of transit vehicles used in Canada today are powered by diesel engines using diesel fuel. In 1979, approximately 80% of the vehicles used by the operating members of the Canadian Urban Transit Association (CUTA) were diesel buses. If one excludes heavy rail or subway vehicles, this figure rises to over 90%.

A diesel engine is a high compression self-igniting engine which commonly operates on a two-stroke cycle. Because of its wide application it is a mass produced product with favourable production costs. In addition, the engine has proven reliability and serviceability both in terms of available parts and trained mechanics. The most commonly used diesel engine in Canadian transit applications is the Detroit Diesel 6V-71, although other makes and models are also used.

The diesel engine is continually undergoing minor improvements and adjustments to increase its efficiency and/or its power output. Detroit Diesel is presently completing the development of a turbo-charged version of the 6V-71 which is expected to improve fuel efficiency by 5-6%. Work is also underway on improving efficiency through electronic sensing and an improved cooling system. A representative of Detroit Diesel estimated that by 1986 the diesel engine will be 10-15% more fuel efficient than today. The potential for improvement depends to some extent on the emission standards in force in the future.

In addition to availability and reliability the diesel engine using diesel fuel has several other advantages, including:

- high energy content in the fuel which provides long range without excessive fuel storage requirements;
- favourable energy costs since the diesel engine is more efficient than most other fuel engines, and diesel fuel is competitively priced with other fuels;

- flexibility in route location and vehicle assignment since the diesel bus does not require a special infrastructure.

The standard urban transit vehicle is not without its disadvantages. These include:

- environmental impacts such as noise and air pollution;
- dependence on crude oil as the prime source of energy.

The performance characteristics of a bus are dependent not only upon the type of propulsion unit but also on the axle ratio and other drive train and vehicle options. The acceleration of diesel powered bus is in the order of 1.0 $m/s^2$ (assuming level ground and half load), and the maximum cruising speed of a diesel bus designed for urban transit service is about 75 km/h. The rate of fuel consumption of a North American diesel powered transit bus is 70-45 litres per 100 km (4-6 mpg) for a standard sized transit vehicle, 80-60 litres per 100 km (3.5-4.5 mpg) for an ADB vehicle, and 40-35 litres per 100 km (7-8 mpg) for a medium sized vehicle. Fuel consumption would be higher in dense urban service or with high air-conditioning loads. It is estimated that an articulated North American diesel bus would consume about 35% more fuel than a standard sized bus.

The only special infrastructure needed to supply the energy requirements of the diesel bus is a fueling station at each bus garage. The cost of such a facility would be small relative to the cost of the garage itself. The manpower requirements of this facility affect the operating and maintenance costs of the diesel bus. The capital cost of a standard diesel bus varies, as would the cost of any type of transit vehicle, depending on both the specific features and options requested as well as the size of the order. Typical costs for a 40 ft. diesel transit bus would be $135,000-$145,000.

Based on maintenance and servicing expenditures made by City of Winnipeg Transit, the maintenance cost for a standard diesel bus was esti-

mated to be $.24/km (1981 dollars). This cost includes maintenance and repairs of items such as: engine, transmission, driveline, suspension, body, tires, oil, electrical components, inspection and washing.

## DIESEL/FLYWHEEL HYBRID

The diesel/flywheel hybrid uses a regenerative braking system to cut fuel consumption by up to 25%. The flywheel is used to recover the tremendous kinetic energy normally dissipated as heat when the bus is braked. After each stop the stored energy is released to accelerate the bus up to cruising speed. Power demands and fuel consumption are greatest during the acceleration phase of operation. Therefore this type of hybrid propulsion is regarded as particularly suitable for large buses with regular stop-start operation in city traffic.

The flywheel is an energy storage device and a power leveller, where the amount of energy stored in the flywheel depends upon the mass and speed of the wheel. The development of higher strength materials has permitted increased rotating speeds and therefore higher energy levels in flywheels. The flywheels which are used in transit vehicle applications have maximum rotating speeds of 10,000-16,000 r.p.m. Since a flywheel reduces in speed as energy is tapped from it, it is necessary to use some sort of continuously variable transmission (CVT) in the drive. The need for a CVT, which has high energy transfer efficiencies in both directions, is one of the major obstacles to the adoption of this technology.

Volvo in Sweden tested a diesel/flywheel hybrid and found that there was no net benefit in terms of fuel consumption due to the component inefficiencies. In Germany, a working group called "Gyrobus" comprised of M.A.N., Daimler-Benz, Bosch and the Technical Universities of Aachen and Berlin are currently developing the flywheel components required for a standard sized urban transit vehicle. Prototype drive systems are being built and installed in several buses and track testing of the vehicles is expected in the near future.

The Urban Transportation Development Corporation (UTDC) is testing the operation of a flywheel in combination with a Detroit Diesel 6V-71 engine. The purpose of the lab tests is to evaluate the propulsion system, highlight potential problems and identify areas where the development is required.

The potential advantages of a diesel/flywheel hybrid propulsion system are:

- reduced fuel consumption;
- lower exhaust emissions and noise pollution during acceleration;
- reduced wear on brake linings.

The main problem with this technology is the complex controls and couplings needed to regulate the combined mechanical efforts of flywheel and engine propulsion during acceleration and cruising. The complexity of the control system results in higher capital and maintenance costs, and can lead to reduced reliability relative to a diesel engine alone.

The performance characteristics and infrastructure requirements of a diesel/flywheel hybrid would be similar to existing diesel buses. Estimates of the cost of the diesel/flywheel hybrid are difficult to make at this time, because the technology is still under development. However, since the technology will potentially reduce fuel consumption by 25%, net additional annual capital and operating costs would have to be less than $2,500 per vehicle before the technology is cost-competitive.

## DIESEL/HYDRAULIC ACCUMULATOR HYBRID

This technology utilizes hydraulic accumulators to recover the kinetic energy lost during braking. A prototype bus has been built in Germany by M.A.N. and this vehicle has undergone factory testing. Route testing of a fleet of vehicles is to be conducted in 1982. In Canada, research has been done by Transport Canada in the area of hydraulic accumulators for auto-

mobiles, however it was concluded that this technology is not suitable for small vehicles. The National Research Council has taken over this program and will examine the potential of hydraulic accumulators in trucks and buses.

The prototype bus uses a variable-displacement swash-plate pump and motor to connect the diesel engine with the drive axle. For normal cruising the engine is coupled to the pump driving a similar motor connected to the axle. When brakes are applied, the engine is automatically decoupled and the intermediate gearing connects a hydraulic pump to the drive wheels. The pump delivers oil to a pair of hydraulic accumulators thereby loading the wheels and retarding the bus. Normal friction brakes on all four wheels remain in use for emergencies, but generally are applied only just before a complete stop.

After a stop the fluid is released from the accumulators to the hydraulic motor. This now drives the wheels without any assistance from the diesel engine, which has been idling since the the start of braking. Stored hydraulic power alone accelerates the bus from rest to 50 km/h, when the engine gradually takes over fully and drives the pump and motor until the next stop. All transmission functions in the braking, acceleration and cruise modes are automatically regulated by a microprocessor system.

The potential advantages of a diesel/hydraulic accumulator hybrid propulsion system are:

- reduced fuel consumption;
- lower exhaust emissions and noise pollution during acceleration;
- reduced wear on brake linings;
- the use of smaller and more economical engines, since additional power can be provided to overcome wind and rolling resistance and to climb gradients.

The main problem with this technology is integrating the hydraulic accumulators into the bus design. The high pressure storage cylinders must be designed to withstand pressures of 33,000 kPa (approximately 4,800 psi),

and must be of sufficient size to accumulate the energy generated by braking. By using a smaller engine, the weight penalty associated with the storage cylinders can be pared down to approximately 200 kilograms.

It is expected that this technology would have performance characteristics similar to a bus equipped with a diesel engine propulsion system. As in the case of the diesel/flywheel hybrid, estimates of the cost of this system are difficult to make because the technology is still under development.

As part of their evaluation of this technology, M.A.N. estimated that a bus equipped with a hydraulic accumulator would cost 15% more than a comparable standard diesel bus. The capital cost of this technology was, therefore, assumed to be $160,000 (1981 dollars).

The application of this technology could reduce diesel fuel requirements by 20-25%, resulting in a fuel cost of $.16 per vehicle kilometre. The saving would be obtained at the cost of increased maintenance due to the complexity of the hydraulic transmission and energy storage systems. Increased maintenance requirements in this area would be partially offset by reductions in brake maintenance. It was assumed that maintenance costs would increase by 4¢ per kilometre due to the additional hydraulic system, and decrease by 1¢ per kilometre due to the reduced brake maintenance requirements. Therefore, maintenance costs would be $.27 per kilometre.

## DIESEL/VEGETABLE OIL ENGINES

In this alternative, vegetable oils such as sunflower or canola oils would be used as supplements to the diesel fuel. Some research is being done in this area, primarily in the use of vegetable oils in farm vehicles. No specific applications or experiments with this technology were identified in the area of transit vehicles.

The advantages of partially substituting diesel fuel with vegetable oils include:

- vegetable oils are a renewable resource;
- vegetable oils are domestically produced;
- the oils have similar characteristics to diesel fuel, and therefore diesel engines would require only minor adjustments.

There are a number of disadvantages associated with substituting diesel fuel with vegetable oils, and these include:

- increased formation of deposits on engine parts;
- vegetable oils have a lower energy content per litre than diesel fuel;
- the cost per litre of vegetable oils is approximately 25% higher than diesel fuel, although this may change in the future.

A transit bus fueled by a mixture of diesel and vegetable oils would have similar performance characteristics and infrastructure requirements when compared with a standard diesel bus. Since modifications to the diesel engine would be minor, the additional costs of using vegetable oils would result primarily from higher fuel costs and engine maintenance costs.

## DIESEL/METHANOL FUEL MIXTURE

Research has been done using methanol as a partial substitute for diesel fuel in diesel engines. Since methanol and diesel fuel do not blend, the fuels are stored separately and emulsified prior to injection in the engine. In tests carried out by the Ontario Research Foundation (ORF) using intercity trucks, up to 30% of the diesel fuel by weight was replaced by methanol. This level of substitution was possible only at cruising speeds in highway operations. Under idling conditions only a small percentage of the diesel fuel could be replaced by methanol. In order to be applied in stop and go transit operations, the control system which governs the fuel mixture would have to be refined so that the proportion of methanol in the mixture could drop very quickly.

The advantages of this alternative relative to the diesel bus include:

- reduced dependence on crude oil, since alcohol fuels can be obtained from a number of sources, both renewable and non-renewable;
- a diesel/methanol mixture can improve thermodynamic efficiencies under certain conditions;
- the total fuel costs of diesel/methanol blends would not be substantially different from the total fuel costs of diesel alone.

The disadvantages associated with this alternative include:

- a sophisticated control system would be required to govern the proportion of methanol in the fuel mixture since transit vehicles are used primarily in stop and go operations;
- some modifications would be required to the diesel engine and the fueling system. The cost of the modifications could be in the order of $5,000 per vehicle;
- with only partial substitution by alcohol fuels, diesel fuel requirements would still be substantial and transit operations would remain dependent upon the availability of diesel fuel.

A diesel transit bus fueled by a diesel/methanol mixture would have similar performance characteristics when compared with a standard diesel bus. As stated above the estimated additional capital costs of this technology would be about $5,000 per vehicle. In addition, there would be increased maintenance costs associated with the system.

## DIESEL/GASEOUS FUEL MIXTURE

Both propane and compressed natural gas (CNG) have been tested as fuel extenders or power boosters to a diesel engine. The gaseous fuels are added to the air stream in the intake manifold of the engine. The use of this technology does not result in any reduction in fuel consumption. As in the case of the diesel/methanol technology, the primary applications of diesel/gaseous fuel mixtures are in intercity trucking operations.

The advantages of this technology include:

- increased security of supply since Canada currently has an excess supply of gaseous fuels;
- gaseous fuels are less costly than diesel fuels in terms of energy content.

The following disadvantages tend to outweigh the above advantages:

- gaseous fuels do not have the energy density of diesel fuel and therefore do not provide the same range per unit volume;
- gaseous fuels reduce the thermodynamic efficiency of the diesel engine;
- at present, the technology results in similar fuel costs when compared with the standard diesel bus due to reduced engine efficiencies.
- transit vehicles would require two separate fuel tanks and two on-board fuel supply systems. In addition, fueling stations would be required for both the diesel and propane fuels.

The performance of a transit bus using a diesel/gaseous fuel mixture would generally be similar to the performance of a standard diesel bus. Improved performance may be obtained in operations which require high power output such as on steep grades.

The cost of this technology would be higher than the cost of a standard diesel bus both in terms of capital and operating costs. Capital costs would increase by approximately $6,000-$8,000 and the increase in operating costs would be the result of higher fuel costs and a small increase in maintenance costs.

## METHANOL/ETHANOL FUELED ENGINES

This technology can involve using a diesel engine fueled primarily (75-85%) by alcohol fuels such as methanol or ethanol. The engine would be ignited by diesel fuel which would be pilot injected immediately before the alcohol fuel was injected. Research in this area is being conducted in both Europe and South America; however, no transit applications of this technology

were identified. This technology would require modifications to the fuel storage system, fuel pumps and injectors. In addition, a control system would take into account the corrosive nature of alcohol fuels. Developmental work is required both in this area, and in improving the ignition characteristics of the alcohol fuels through the use of various additives.

Research is also being performed on the use of alcohol fuels in spark-ignited vehicle engines. In West Germany, M.A.N. has tested a prototype transit vehicle powered by a modified version of one of their standard diesel engines. The engine combines the fuel injection system and high compression ratio associated with a diesel engine with a spark plug to ignite the charge. In tests performed using methanol, this option was found to improve thermal efficiency by 5% relative to a standard diesel engine used on a similar vehicle. Tests were also performed with ethanol and similar results were achieved. The engine design overcomes the cold starting problems often associated with alcohol fuels and permits cold starting at temperatures of -20°C.

The advantages of this technology include:

- reduced dependence on crude oil, since alcohol fuels are obtained from other sources, both renewable and non-renewable;
- reduced emissions since alcohols are clean burning fuels. If additives are required to the fuels this advantage may be lost.

Some of the disadvantages of this technology would be:

- the spark ignition and pilot injection systems are more complex than the system required for diesel fuel alone, and therefore may result in increased maintenance costs;
- it is yet to be determined if this technology is suitable for stop and go transit operations.

It was assumed that the performance of this technology would not be substantially different from the performance of a standard bus. It was further assumed that the capital cost of a standard transit vehicle equipped

with a production model of an alcohol engine would be $145,000 (1981 dollars) based on conclusions drawn in a paper on alcohol-fueled buses by A. Neitz of M.A.N. AG of West Germany.

The maintenance costs of alcohol engines would be somewhat higher than comparable costs for diesel engines due to the addition of a spark-ignition system or a second fuel injection system. In addition, the corrosive nature of alcohol fuels may result in more frequent maintenance and replacement requirements for certain components of the engine. On the basis of these factors, it was assumed that maintenance costs for this option would be $.26 per kilometre.

## GASEOUS FUEL ENGINES

During the 1950's and 1960's, the Chicago Transit Authority (CTA) operated an extensive fleet of propane powered buses. At the peak, CTA had over 2,600 propane buses. At the time, CTA used propane because of the low cost of the fuel relative to diesel. The engines used on the propane buses were modified gasoline engines with maintenance costs similar to comparable diesel engines. The overall engine life was similar to that of diesel engines as well, except that there were some problems with cracking of heads and burning of valves.

Since propane is a gas at normal temperatures and pressures and is usually stored in pressurized containers, fueling operations can be more dangerous than with other fuels. During the period when CTA operated propane buses they had one major accident related to the use of propane.

More recently, European bus manufacturers have begun to produce propane powered vehicles. Both M.A.N. in West Germany and Sauer in Switzerland have modified their regular diesel engines to operate with propane by adding a spark ignition system and reducing the compression ratios. In North America, Ford and International Harvester are selling trucks with factory conversions of gasoline engines to propane.

Based on current European experience, propane buses operate with a thermal efficiency 10% lower than standard diesel buses. Since 1.65 litres of propane are required to yield the same heat energy as one litre of diesel, fuel costs for a propane bus would be cheaper than for a diesel bus only if propane were priced at less than 60% of diesel fuel.

Because CNG requires six times more volume than diesel fuel to provide the same range, it is not considered to be as viable an alternative as propane. This problem may be overcome through the use of liquified natural gas (LNG). Developmental work is presently being done in the areas of cryogenic fuel storage and handling. The feasibility of LNG as an alternative fuel depends on the successful completion of this work.

The advantages of using propane technology include:

- increased security of supply since Canada currently has a surplus of propane;
- although propane has a lower energy content per unit volume and is thermodynamically less efficient than diesel fuel, its lower cost makes propane competitive with diesel fuel in terms of total fuel costs;
- propane is a clear burning fuel and would therefore reduce air pollution and odour relative to a diesel bus.

The disadvantages of using propane powered engines in urban transit service include:

- gasoline engines, which can be converted to propane quite easily, are generally not built with the same durability as diesel engines;
- diesel engines, although more durable, require extensive modifications before they can use propane. In fact, after conversion they no longer operate using a diesel cycle but rather a spark ignited Otto cycle;

Propane powered buses would have performance characteristics similar to those of a standard diesel bus. Propane engines, which are often modified gasoline engines, could be up to $5,000 cheaper than diesel engines

with the same power rating, based on estimates provided by Ford of Canada. Therefore, the capital cost of a propane powered vehicle was estimated to be $135,000 (1981 dollars).

Relative to a diesel engine, a propane engine would save on oil requirements and would not have a fuel injection system to maintain. However, unlike the diesel engine the propane engine would have a spark ignition system which would require maintenance. Overall it is expected that the maintenance costs for a propane powered bus would be similar to the corresponding costs for a diesel powered bus.

## HYDROGEN FUELED ENGINE

The use of hydrogen as a fuel for transit vehicles is being examined in a three phase development program which is being conducted by UTDC over the next five years. The first phase of the program, which is presently underway, involves an investigation of the problems associated with this technology and a feasibility analysis of the long-term potential of the technology. This will lead to a hardware development program and ultimately, the production of two prototype buses in 1986. Development work is required in the areas of fuel storage, both off and on vehicle, refueling and engine design.

The advantages of this technology include:

- hydrogen can be produced by electrolysis using hydroelectric power during off-peak periods;
- hydrogen is a clean burning fuel which produces mainly water during combustion.

The major disadvantages of this alternative are as follows:

- in order to provide an adequate range, the hydrogen must be stored in a liquid state or in a chemically combined state such as hydrides. This requires the development of suitable cryogenic storage and handling techniques, or less expensive hydrides than currently available;

- this technology is still in a conceptual stage of development and therefore it cannot be adequately evaluated relative to other technologies.

Information on performance and cost characteristics of this technology are not yet available. However, the intent of the UTDC development program is to produce a transit bus with performance characteristics similar to existing diesel buses.

**K-CYCLE ENGINE**

The K-cycle engine is being developed by Kristiansen Cycle Engines Limited of Winnipeg. In the K-cycle engine, the power and exhaust strokes can be up to four times as long as the intake and compression strokes. The engine is much smaller and about two-thirds lighter than conventional combustion engines with the same power output. Based on lab tests, the K-cycle engine is expected to reduce fuel consumption by 25-50% when compared with a conventional gasoline engine. Four prototype models of the engine have been built and development work is continuing to overcome some of the problems associated with the engine. The resolution of these problems will determine the timing of more extensive field trials. Development work on this engine is also being performed in Italy under license, and pre-production models are expected in two to three years.

The advantages of the K-cycle engine include:

- reduced fuel consumption;
- reduced engine vibrations and lower noise levels;
- reduced emission of waste gases due to a longer combustion stroke.

The disadvantages which the K-cycle engine must overcome before it becomes a viable technology include:

- the engine is subject to strong centrifugal forces which do not develop in conventional engines. Lightweight but durable parts must be developed to lessen the uneven wear created by these forces;

- an effective sliding seal system must be developed to cope with the unusual stresses produced by a rotating engine;
- there is no operating experience with the K-cycle engine, therefore the reliability and durability of the engine is unknown.

The K-cycle engine produces higher torque at low r.p.m. when compared with conventional engines. This characteristic is highly suitable for the stop and go operations of transit buses, and would result in higher rates of acceleration. The cost of a K-cycle engine depends to a large extent on production levels and would be difficult to estimate at this time. Maintenance costs would also be difficult to estimate because of the radically different design of the K-cycle engine.

## STANDARD TROLLEY COACH

Standard trolley coaches use compulsion systems which involve a very simple arrangement whereby overhead power at a nominal 600 volts D.C. is fed to an electric motor. Trolley coach motors fall into three types, the traditional D.C. compound motor, series wound D.C. motors, and A.C. induction motors. There are several specific trolley coach motors manufactured in North America. The GE 1213 and the Westinghouse 1442 are similar compound motors with a continuous power rating of 116 kW (155 hp) and an insulation class of "H" which permits high internal temperatures without damage to the motor and allows the motor to provide substantial output beyond its rated power. Westinghouse also produces a high power D.C. series motor, the 1459. Several makes of AC induction motors are potentially adaptable to trolley coaches.

The control system on a trolley coach must adjust the voltage across the motor to a low level for starting and then raise it in stages to full voltage at operating speeds. There are three basic types of control equipment: switched resistor with a D.C. motor, thyristor chopper with a D.C. motor, and pulse width modulation with an A.C. motor which varies frequency as well as voltage. Certain combinations (hybrids) are available between switched resistor and thyristor chopper controls, but these are general-

ly regarded now as obsolete except for retrofit purposes. The most common control unit used in North America is the General Electric type MRC control, a cam-controlled switched resistor design with automatic acceleration. However, advances in solid state design have made the MRC control obsolete. The last four major trolley bus orders in North America (Philadelphia, Seattle, Edmonton and Vancouver) all selected 'chopper' controls after life cycle cost analysis.

A significant advantage of trolley coaches is that the motor can be used as a generator to provide braking, thus reducing wear and maintenance on the pneumatic friction brake. The electrical energy generated during braking can be either returned to the overhead line (termed regenerative or recuperative braking) or dissipated in resistors (termed dynamic braking). Regenerative braking is discussed in the next section.

The advantages of a trolley coach relative to a standard diesel bus include:

- trolley coaches use electricity as a power source. In Manitoba a large proportion of the electricity is generated by hydro-electric installations, and therefore is a renewable resource;
- trolley coaches reduce emissions and noise levels and improve the quality of the ride;
- lower total fuel costs, based on the costs of diesel and electricity in Winnipeg;
- longer engine life as compared with diesel buses. Lower stresses and vibrations result in longer vehicle body lives as well;
- lower maintenance requirements and potentially fewer road calls;
- possible outdoor storage.

Some of the disadvantages associated with trolley coach operations include:

- the overhead wire required to supply power is both costly to install and visually intrusive;
- there is reduced flexibility in the routing of trolley coaches. This can cause significant delays when accidents or other disruptions occur along the route, but can be overcome by equipping the vehicle with an on-board power supply or engine for emergency off-wire service;
- trolley coach systems can be more expensive on a per kilometre basis to maintain when compared with diesel buses, if the maintenance costs of the overhead wire system are included, and the density of operations is low.

Trolley coaches can offer higher rates of acceleration than diesel buses. In addition, if solid state controls are used the acceleration is very smooth. Trolley coaches have a lower maximum cruising speed since the chances of dewirement increase at speeds over 55 km/h. The cost of a trolley coach vehicle is in the range of $200,000 to $250,000. Approximately 40% of this cost is for the propulsion and control unit. In addition, trolley coaches require a power supply infrastructure which costs approximately $400,000 per kilometre. These costs may be reduced if existing poles and buildings may be used to support the overhead wire. For the purposes of comparison with diesel bus operations, these costs should be allocated to the trolley coaches using the route. In Winnipeg, the power costs per kilometre of a trolley coach would be substantially lower than the fuel costs for a diesel bus, but is expected that the overall maintenance costs would be similar, if the maintenance of the overhead is included and the density of operation is sufficiently high.

## TROLLEY COACH WITH REGENERATIVE BRAKING

This technology is identical to the standard trolley coach except for the control system.

Regeneration involves returning the electrical energy generated during braking to the overhead line. However, this return is only possible when the line is receptive, that is, when another power absorbing source, usually an accelerating trolley coach, is nearby. Regenerative braking is not possible on overhead sections where there is no power, such as at swit-

ches, cross-overs, and isolation points. When power cannot be returned to the line it must be absorbed on board or mechanical braking used.

The primary advantage of this technology over the standard trolley coach is the reduction in energy consumption. The cost of this advantage is increased complexity of the control system, and potentially higher maintenance costs, although recent development in microprocessor logic have reduced or eliminated this disadvantage.

The performance of a trolley coach with regenerative braking would be identical to that of a standard trolley coach. Capital and maintenance costs of this technology would be only marginally higher than the standard trolley coach, while energy costs would be 25% to 45% lower. The general consensus among manufacturers and operators has been that regenerative braking is not cost-effective, however recent experience with regenerative braking in Toronto (rail) and France (trolley bus) indicates otherwise. The City of Vancouver will shortly be receiving 250 new coaches with full regeneration and is retrofitting 50 1975 coaches with new regenerative propulsion systems.

## TROLLEY COACH/DIESEL HYBRID

Three types of trolley/diesel hybrid buses can be distinguished:

1. The Swiss type: a small gasoline engine is fitted into the trolley coach to provide emergency off-wire service.

2. The French Berliet type: a somewhat larger diesel engine is used on the Berliet ER100 trolley coaches to provide limited off-wire capabilities (maximum 50 km). The diesel engines are intended for emergency use, although some systems are using the off-wire capabilities on a scheduled basis.

3. The German Duo-Bus: the German trolley/diesel Duo-Bus manufactured by Daimler-Benz is designed to operate with or without overhead line with the same performance characteristics.

In the case of the first two types of vehicles there is a trade-off between the additional capital costs, marginally higher maintenance and oper-

ating costs and the improved flexibility in operations and reduced requirements for overhead redundancy. For the purposes of evaluation, these two types of vehicles can be treated as extensions of the standard trolley coach. The third type of trolley/diesel hybrid is substantially different from a standard trolley coach and is examined in the remainder of this section.

In the DUO-Bus a transfer gear is connected with either the diesel engine or with the electric motor by means of two mechanical clutches. Starting and speed control are achieved by means of a conventional automatic transmission which connects the transfer gear with the drive axle. In order to allow for the transfer from one power source to the other without interruption, an automatic control is provided to actuate the current collectors.

The advantages of this technology include:

- the substitution of diesel fuel by hydro-electric power;
- flexibility in route design and operations; for example, extra or emergency turnbacks can be made without additional overhead;
- the ability to use overhead wire power supply on route sections where bus frequencies are high, and diesel power on the feeder portions of the route;
- the ability to leave out expensive or difficult parts of the overhead, for example at complex juctions, although this may not be practical in many cases.

Some of the disadvantages include:

- inefficiencies in operation since under each mode of operation a spare engine must be carried about;
- high capital costs split between power supply and the additional engine and control mechanisms;
- potentially higher maintenance costs since both motors would require servicing.

The performance of this vehicle would be similar to a trolley coach when operating under electric power and similar to a diesel bus when powered by the diesel engine. Acceleration rates and maximum speeds may be slightly reduced due to the increased vehicle weight. The cost of a trolley/diesel bus would be greater than the cost of a trolley bus alone, however, the power supply infrastructure requirements would be lower. Based on estimates in a paper on the Daimler-Benz DUO-bus, the life cycle costs (exclusive of driver and administrative costs) of a trolley/diesel bus would be about 60% higher than the costs of a diesel bus but 25% lower than the costs of a standard trolley coach.

## TROLLEY/BATTERY BUS

As in the case of the trolley/diesel bus, there are various types of trolley/battery buses which can be distinguished on the basis of their off-wire performance. Trolley/battery buses with limited off-wire capabilities suited for emergency use only can be treated as special cases of the standard trolley coach. Vehicles which provide full service under either trolley or battery operation are examined in the remainder of this section.

In addition to developing a trolley/diesel bus, Germany has also developed and is presently operating, a trolley/battery bus. This vehicle is also called a DUO-Bus. When driving "off-wire" the bus draws energy from a traction battery, and when driving "on-wire" the traction energy and energy required for recharging the battery is drawn from overhead wires. In addition, the vehicle makes use of regenerative braking when the battery has a low charge. As in the case of the trolley/diesel DUO-Bus, the vehicle has an automatic power collector device which is used to connect and disconnect it from the overhead wires.

The advantages of this technology are similar to the previous alternative, and include:

- complete substitution of diesel fuel by hydro-electric power;
- flexibility in route design and operations;

- ability to use overhead wire supply on route sections with high bus frequencies, and battery power on the feeder portions of the route.

The disadvantages of the technology include:

- reduced efficiency due to increased vehicle weight. The battery weight comprises 15% of the total vehicle weight;
- high capital costs are split between the power supply system and the on-board battery;
- higher recurring annual costs due to the one year life of the battery.

The performance of the vehicle is similar to the performance of a standard trolley coach. Based on estimates presented in the paper referenced in the previous section, the life cycle costs (excluding the driver and administrative costs) of a trolley/battery bus would be 130% higher than similar costs for a diesel bus alone, and marginally higher than the costs of a standard trolley coach.

## TROLLEY/FLYWHEEL BUS

Flywheels can be used in combination with trolley coaches to allow for regenerative braking and emergency off-wire service, or extensive off-wire service. A development program sponsored by the Department of Energy and the Department of Transportation of the United States is aiming at developing prototype vehicles in the latter category. Both General Electric and Garrett Airesearch have developed flywheel energy storage systems (FESS) under contract, and hope to produce prototype vehicles with two years. After the prototype vehicles have been tested a small fleet of 10 to 20 vehicles will be produced and tested in service. As presently designed, the vehicles should be able to travel between three and five miles under flywheel power before recharging is required. This range would be reduced if there are uphill grades, heavy loads or heavy heating or air conditioning requirements. Recharging could either be stationary or along a route tangent. A stationary recharge would take about 90 seconds, while an en-route recharge would require less than half a mile of overhead wire.

The advantages of this technology include:

- diesel fuel requirements would be replaced completely by hydro-electric power;
- a trolley/flywheel bus would allow for flexibility in route design and operations;
- emissions and noise levels would be reduced, and there are reduced requirements for extensive overhead wire infrastructure which can be visually intrusive.

The disadvantages associated with the trolley/flywheel bus include:

- high capital cost for the vehicle as well as some power supply infrastructure requirements;
- uncertain maintenance requirements since the reliability and durability of the flywheel system is still untested;
- the present design may require supplemental heating units for Winnipeg conditions.

The performance of this vehicle technology is expected to be similar to the performance of a standard trolley coach. Cost estimates have been made by both General Electric and Garrett Airesearch and these estimates show that the trolley/flywheel bus has a lower life cycle cost than a standard trolley coach. However, the validity of these estimates is questioned by others in the trolley coach industry. The cost of this technology relative to the diesel bus depends upon the cost of diesel fuel and of electrical energy, as well as the fuel efficiency of the diesel bus. Based on different assumptions, G.E. and Garrett estimate that the trolley/flywheel bus would have life cycle costs equal to or somewhat higher than the diesel bus. This conclusion depends on an optimistic estimate of the capital cost of such a vehicle.

**BATTERY BUS**

In order to power a standard bus solely by battery without recharging during the day, a battery capacity of some 200 kWh would be required for

daily bus operations of 150 km. A lead acid battery of this capacity would weigh 9 tonnes and a battery bus clearly would be impractical for this range. One approach to overcome this problem is to carry the battery in a trailer behind the vehicle and exchange trailers when the battery has become discharged, M.A.N. has built a prototype bus using this design; however, the high costs of batteries limit the potential of this technology. National Bus Company in the United Kingdom has extensively tested a similar prototype and concluded that the vehicle was not viable due to its high cost, relatively poor reliability and limited range.

Other battery buses, manufactured by Seddon and Lucas underwent operational testing during the 1970's in a number of cities in the United Kingdom, including Manchester and South Yorkshire. In these tests, the major problem identified was the limited range of the vehicles.

An alternative approach is to use more efficient batteries such as the sodium-sulphur cell. A sodium-sulphur cell with a capacity of 200 kWh would weigh approximately 1 tonne. Such a battery would have a peak output rating of approximately 130 kWh, which is comparable to the power needs of a trolley bus. Presently, the sodium-sulphur cell is still under development and the cost of this type of battery is uncertain. In addition, since the cell will only operate when the sodium-sulphur and sodium-sulphide are molten, it must be heated to 300°C. This introduces a number of design problems since there must be adequate protection of the battery against collision damage. Other high energy batteries are under development but commercial availability may be a decade away.

The advantages of a battery bus include:

- the vehicle would use electric power as opposed to diesel fuel as an energy source;
- the vehicle would operate with complete freedom from power supply infrastructure;
- a battery bus has the same emission and noise advantages as a trolley coach.

There are a number of significant disadvantages to the battery bus, and these include:

- battery weight and insufficient range with existing batteries;
- high capital cost for the vehicle, and high recurring costs since the battery must be replaced annually, given current technology. Deep discharge batteries with extended life are under development;
- batteries with higher energy storage capacities are still under development and have a number of technological and safety problems which must be overcome.

The performance of a battery bus would be similar to that of a trolley coach if the battery had a sufficient peak output rate. Cost estimates of the battery bus made by English and German authors indicate that the life cycle costs (excluding driver and administrative costs) would be more than twice as high as comparable costs for the diesel bus, but developments in battery technology may potentially reduce or remove this differential in the longer term.

## HYDROGEN FUEL CELL BUS

This technology would use electricity generated through an electrochemical reaction using hydrogen to power a transit bus. The feasibility of this technology is being examined as part of the UTDC research and development program which is looking at the use of hydrogen as an alternative transportation fuel. Since the first task of the R and D program is to define the concept, an assessment of this technology cannot be made at this time. However, it can be concluded that this alternative requires considerably more technological development before it could be considered as an alternative to the diesel bus.

## LIGHT RAIL TRANSIT (LRT)

Light Rail Transit is a confusing term, since these vehicles are often not substantially lighter or less costly per unit capacity than conventional rapid transit equipment. The main potential for cost-savings with

an LRT system comes from a reduction in the fixed guideway requirements. An LRT vehicle obtains its power supply from an overhead catenary as opposed to the third rail pick-up used by conventional rapid transit. This allows LRT vehicles to use at-grade intersections and permits lower level (i.e. street) loading.

In Canada, LRT systems now operate in Calgary, Edmonton and Toronto. The advantages of this technology include:

- its use of electrical power;
- improved performance and ride characteristics compared to diesel buses;
- reduced emissions;
- higher potential capacity.

The disadvantages of an LRT system include:

- high capital costs for both the vehicles and the required infrastructure;
- higher maintenance costs because of the need to maintain both vehicles and right-of-way;
- no flexibility in terms of emergency route changes or route relocation.

The performance of an LRT system is determined primarily by the degree of right-of-way separation. In general the acceleration rates of an LRT lie between those of a diesel bus and a trolley coach, while the maximum cruising speed is similar, or higher than, that of a diesel bus. There is considerable variation in the costs of light rail vehicles depending upon the degree of technical sophistication involved in the vehicle specifications. Individual vehicle prices are also influenced by the quantity ordered and the degree to which specifications vary from available equipment. Typical costs range from $700,000 to $1 million per vehicle. The required power supply and rail infrastructure would cost over $4 million per route kilometre.

## INTERMEDIATE CAPACITY TRANSIT SYSTEM (ICTS)

Intermediate Capacity Transit System (ICTS) refers to technologies that have the capability of providing capacities that are greater than those provided by surface transit technologies and smaller than those attainable with conventional rapid transit technologies such as subways. UTDC has developed such a technology and plans are well underway to implement ICTS systems in Vancouver and Toronto. This system can provide capacities in the range of 5,000 to 25,000 passengers per hour per direction. For low capacity applications small vehicles of approximately 9 meters in length can be operated either singly or in short trains. For high capacity applications larger vehicles of 15 metres in length can be operated in trains of up to six vehicles. The combination of train capacity variations and operating headways down to 60 seconds provides the large capacity range. The proposed ICTS systems will use linear induction motor propulsion with regenerative braking, and will be automatically controlled. Optionally, the UTDC system may utilize traction motor drives, manual controls and a simplified signalling system.

The advantages of this technology relative to other technologies include:

- the use of electric power;
- improved performance and ride characteristics;
- reduced emissions and noise levels;
- high potential capacity;
- improved traction and braking associated with the linear induction motor.

The disadvantages of this system are similar to those of the LRT and include:

- high costs for vehicle and infrastructure requirements;
- potentially negative impact on adjacent areas;

- potentially high maintenance costs;
- no flexibility in route relocation.

The performance of the ICTS would be similar to the performance of an LRT vehicle, except on steep grades where the linear induction motor would provide better performance. The costs of this technology would lie between the costs of an LRT system and those of a heavy rail rapid transit system.

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| Saab - Scania<br>Scania Division<br>Sodertalje, Sweden | Rolf Lindstrom | - diesel buses and trolley coaches |
| Lucas - Cloride<br>Electric Vehicle Systems<br>Evelyn Road<br>Birmingham, England | C. G. Harding | - battery buses |
| Daimler-Benz AG<br>Postfach 202<br>D-7000 Stuttgart 60<br>West Germany | Dr. C. Bader<br>0711/3021 | - diesel buses, trolley coaches, hybrid diesel and electric buses |
| Transurb Consult<br>rue des Colonies 2-4<br>1000 Brussels<br>Belgium | Yvan Flecijn<br>511.25.72 | - rapid transit systems |

# APPENDIX B

## COSTING OF ALTERNATIVE INFRASTRUCTURE/TECHNOLOGY SYSTEMS

## COSTING OF ALTERNATIVE INFRASTRUCTURE/TECHNOLOGY SYSTEMS

In this section the relative costs of buses, LRT and ICTS are compared. The comparison has been made on the basis of the calculations described below.

First the vehicle operating costs per vehicle kilometre are calculated by the following formula:

$$VOC = \left(\frac{GDW}{s} + F + OP\right) OVHD + \left(\frac{FVC \times OVHD + AVCC \times SP}{k}\right)$$

Where:

| | |
|---|---|
| VOC | is the vehicle operating costs per vehicle kilometre |
| GDW | is the operator's gross wages per hour including allowance for fringe benefits, scheduling inefficiencies, shift premiums, etc. |
| s | is the average operating speed |
| F | is fuel cost per vehicle kilometre |
| OP | is operating and maintenance costs per vehicle kilometre |
| OVHD | is an overhead factor to take account of fixed administrative overhead |
| FVC | is fixed per vehicle cost in dollars per vehicle per year |
| AVCC | is the annualized vehicle capital costs per vehicle |
| SP | is a factor to take account of the need for spare vehicles |
| k | is the annual average number of kilometres operated by a vehicle in a year. |

To reduce this to an operating cost per unit of capacity provided, this vehicle operating cost is divided by C, the scheduled capacity of the vehicle.

To examine the infrastructure costs the following formula was used:

$$IC = \frac{AICC + AIMO \times OVHD}{C \overline{\frac{NP}{x}} \; s \times K}$$

$$= \frac{AICC + AIMO \times OVHD}{(C \times NP) \times K/s}$$

Where:

| | |
|---|---|
| IC | is the infrastructure cost per unit of capacity provided in dollars per place-kilometre |
| AICC | is the annualized infrastructure capital cost |
| AIMO | is the annual infrastructure maintenance and operational costs |
| C | is the scheduled capacity per vehicle |
| NP | is the number of vehicles provided in the peak hour |
| s | is the average operating speed |
| K | is the annual number of vehicle kilometres operated by a vehicle. |

It should be noted that (C x NP) represents the capacity provided in an hour.

Exhibit B-1 shows the values assumed for each of the five vehicle technologies examined and the results. Most of these costs have been developed from material presented in Chapter 4. Other costs have been derived from analyses of actual performance transit systems. All the information is expressed in 1981 dollars.

The one variable that requires some explanation is the scheduled capacity per vehicle. A standard bus offers between 51 and 53 seats. With reasonable standards of comfort for standing passengers the total design capacity of a bus is between 75 to 80 passengers. Over an hour's time, however,

## exhibit B-1

## Cost Assumptions and Comparative Results

| | BUS ON STREET | LRT ON STREET | BUS ON BUSWAY | LRT ON SEPARATE RIGHT-OF-WAY | ICTS |
|---|---|---|---|---|---|
| **VEHICLE COSTS** | | | | | |
| Gross Driver's Wages - GDW ($/hr) | 13.50 | 13.50 | 13.50 | 13.50 | - |
| Average Operating Speed - s (km/hr) | 20 | 20 | 40 | 40 | 40 |
| Fuel Cost - F ($/veh-km) | .20 | .07 | .20 | .07 | .07 |
| Vehicle Operating and Maintenance Cost - OP ($/veh-km) | .24 | .30 | .24 | .30 | .42 |
| Overhead Factor - OVHD | 1.16 | 1.16 | 1.16 | 1.16 | 1.16 |
| Fixed Vehicle Costs - FVC ($/veh/year) | 6,000 | 6,000 | 6,000 | 6,000 | 6,000 |
| Annualized Vehicle Capital Cost - AVCC ($/veh/year) | 12,600 | 45,000 | 12,600 | 45,000 | 52,000 |
| Spare Vehicle Factor - SP | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Vehicle Mileage per Year - k (km/veh/year) | 50,000 | 50,000 | 60,000 | 60,000 | 60,000 |
| Total Vehicle Operating Cost - Calculated - VOC ($/km) | 1.71 | 2.34 | 1.25 | 1.76 | 1.64 |
| Vehicle Capacity - C (places/vehicle) | 60 | 110 | 60 | 110 | 75 |
| Calculated Vehicle Cost per Place-km (¢) | 2.85 | 2.13 | 2.08 | 1.60 | 2.18 |
| **INFRASTRUCTURE COSTS** | | | | | |
| Annualized Infrastructure Capital Cost - AICC ($/lane-km/year) | - | 140,000 | 300,000 | 465,000 | 435,000 |
| Annual Infrastructure Maintenance Cost - AIMO ($/lane-km/year) | - | 5,000 | 20,000 | 25,000 | 30,000 |
| Vehicle Mileage Per Year - k (km/veh/year) | - | 50,000 | 60,000 | 60,000 | 60,000 |
| Average Operating Speed - s (km/hr) | - | 20 | 40 | 40 | 40 |
| (AICC + AIMO x OVHD)/(K/S) - Calculated (dollars) | - | 58.32 | 215.46 | 329.33 | 313.20 |
| Infrastructure Cost Per Place-km - IC (¢/place-km) | | | | | |
| @ capacity of 1,000 places/hr | - | 5.83 | 21.55 | 32.93 | 31.32 |
| @ capacity of 5,000 places/hr | - | 1.17 | 4.31 | 6.59 | 6.26 |
| @ capacity of 10,000 places/hr | - | 0.58 | 2.15 | 3.29 | 3.13 |
| **TOTAL COST PER PLACE-KM (¢)** | | | | | |
| @ capacity of 1,000 places/hr | 2.9 | 8.0 | 23.6 | 34.5 | 33.5 |
| @ capacity of 5,000 places/hr | 2.9 | 3.3 | 6.4 | 8.2 | 8.4 |
| @ capacity of 10,000 places/hr | 2.9 | 2.7 | 4.2 | 4.9 | 5.3 |

each vehicle would not be filled to capacity because of variations in the flow and variations in the movement of buses. Therefore, a lower figure should be used in developing an average loading to be used in this calculation. An analysis of passenger loadings in the south-west and west corridors in 1980 and 1981 shows that peak hour loadings average 54 passengers per bus. For a high density transit way or transit bus corridor this could probably be increased by careful scheduling and by more uniformity of bus flows. We therefore, have chosen 60 passengers per bus as a measure of the average capacity of a bus over the peak hour.

An LRT vehicle similar to that used in Calgary and Edmonton has the design capacity of 146 passengers with low platform loading. Assuming a similar ratio of average hourly usage we have estimated the hourly design capacity to be 110 places per vehicle. Similar calculations resulted in an estimate of 75 places per vehicle as the hourly des'gn cpacity of an ICTS vehicle system.

# APPENDIX C

## COMPARISON OF VARIOUS BUS TECHNOLOGIES

## COMPARISON OF VARIOUS BUS TECHNOLOGIES

In order to compare the various bus technologies, cost equations were worked out. In this case only costs that would vary from one technology to another were included in this analysis. Therefore, administrative overheads, drivers' wages, storage costs and other factors which were not likely to change were not included.

Assuming that a 10% allowance for spares is required, the number of buses that are needed per route-kilometre can be calculated as follows:

$$N = \frac{120 \times 1.1}{h \times s}$$

Where:

N is the number of buses required per route-kilometre for service in both directions

h is the peak headway in minutes

s is the average peak hour speed in kilometres per hour.

Assuming that all vehicles operate the same number of kilometres per year, shown as K in the equations, then the bus kilometres required per route-kilometre per year are:

$$B = K \times \frac{132}{h \times s}$$

For a bus requiring no infrastructure along the route the relevant costs per bus kilometre are therefore as follows:

$$\text{Variable Cost Per Bus Kilometre} = F + OP + \frac{AVCC}{K}$$

Where:

F is the fuel costs per bus kilometre

OP is the operating and maintenance cost per bus kilometre

K is the average number of kilometres operated by a vehicle in a year

AVCC is the annualized vehicle capital cost per vehicle.

For vehicles requiring some infrastructure for providing power to the vehicle, the variable cost per bus kilometre can be calculated as follows:

$$\text{Variable Cost Per Bus Kilometre} = F + OP + \frac{AVCC}{K} + \frac{(M + AICC) \times PRP}{K \times N}$$

Where:

M is the annual maintenance cost of the power supply in dollars per kilometre per year

AICC is the annualized capital costs of the infrastructure in dollars per kilometre year

PRP is the proportion of the route which has to be provided with infrastructure.

It should be noted that the last term of this equation is dependent upon the headway of the route.

Exhibit C-1 gives the assumptions made for each technology and the results. For all of the different types of buses the following standard elements were used:

K = 50,000 kilometres per vehicle per year

s = Average speed of 20 kilometres per hour

## exhibit C-1

## Comparison of Alternative Bus Technologies (Current Fuel Prices )

| COST ELEMENT / TECHNOLOGY | VEHICLE COSTS | | | | INFRASTRUCTURE COSTS | | | | TOTAL COSTS ($/veh-km) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fuel ($/km) | Operating and Maintenance ($/km) | Annualized Capital Cost ($/Year) | Total ($/km) | Maintenance Costs ($/yr/route-km) | Annualized Capital Cost ($/yr/route-km) | Proportion of Route Electrified | Total (M+AICC).PRP ($/yr/route-km) | @ 15 Min. Headway | @ 10 Min. Headway | @ 5 Min. Headway | @ 2 Min. Headway |
| Standard Diesel | .20 | .24 | 12,600 | .69 | - | - | - | - | .69 | .69 | .69 | .69 |
| Diesel/Hydraulic Acc. | .16 | .27 | 14,500 | .72 | - | - | - | - | .72 | .72 | .72 | .72 |
| Diesel/Methanol | .20 | .25 | 13,000 | .71 | - | - | - | - | .71 | .71 | .71 | .71 |
| Diesel/Propane | .21 | .25 | 13,200 | .72 | - | - | - | - | .72 | .72 | .72 | .72 |
| Methanol/Ethanol | .21 | .25 | 13,000 | .72 | - | - | - | - | .72 | .72 | .72 | .72 |
| Propane | .22 | .24 | 12,200 | .71 | - | - | - | - | .71 | .71 | .71 | .71 |
| Standard Trolley Coach | .06 | .19 | 12,300 | .49 | 8,000 | 23,100 | 1.00 | 31,100 | 1.90 | 1.43 | .96 | .68 |
| Trolley Coach/ Regenerative Braking | .05 | .19 | 12,300 | .48 | 8,000 | 23,100 | 1.00 | 31,100 | 1.89 | 1.42 | .95 | .67 |
| Trolley/Battery | .08 | .22 | 20,900 | .72 | 8,000 | 23,100 | 0.50 | 15,550 | 1.43 | 1.19 | .96 | .81 |
| Trolley/Diesel | .14 | .24 | 15,400 | .69 | 8,000 | 23,100 | 0.50 | 15,550 | 1.40 | 1.16 | .93 | .78 |
| Trolley/Flywheel | .06 | .22 | 16,600 | .61 | 8,000 | 23,100 | 0.15 | 4,665 | .82 | .75 | .68 | .64 |

Exhibit C-1 gives the cost assumptions and results using existing fuel costs. A second analysis was performed using future fuel costs. In this case the price of diesel fuel was increased by 36%. Estimates were made of the future costs of propane and alcohol fuels relative to diesel fuel. Electricity was maintained at its current price level. The results are shown in Exhibit C-2.

**exhibit C-2**

**Comparison of Alternative Bus Technologies (1999 Fuel Prices)**

| | FUEL COSTS ($/km) | TOTAL COSTS ($/VEH-KM) @ 15 Min. Headway | @ 10 Min. Headway | @ 5 Min. Headway | @ 2 Min. Headway |
|---|---|---|---|---|---|
| Standard Diesel | .27 | .76 | .76 | .76 | .76 |
| Diesel/Hydraulic Accumulator | .22 | .78 | .78 | .78 | .78 |
| Diesel/Methanol | .24 | .75 | .75 | .75 | .75 |
| Diesel/Propane | .26 | .77 | .77 | .77 | .77 |
| Methanol/Ethanol | .21 | .72 | .72 | .72 | .72 |
| Propane | .27 | .76 | .76 | .76 | .76 |
| Standard Trolley Coach | .06 | 1.90 | 1.43 | .96 | .68 |
| Trolley Coach/Regenerative Braking | .05 | 1.89 | 1.42 | .95 | .67 |
| Trolley/Battery | .08 | 1.43 | 1.19 | .96 | .81 |
| Trolley/Diesel | .17 | 1.43 | 1.19 | .96 | .81 |
| Trolley/Flywheel | .06 | .82 | .75 | .68 | .64 |

# APPENDIX D

## COSTING OF INFRASTRUCTURE FOR ELECTRIC TRACTION SYSTEMS

# COSTING OF INFRASTRUCTURE FOR ELECTRIC TRACTION SYSTEMS

In this appendix the capital and operating costs of the infrastructure for the different electric traction systems are examined. Two sets of systems are looked at, the 1999 "options" as described in Chapter 6 and the 1987 "alternatives" described in Chapter 9 of the main report.

## 1999 OPTIONS

Costing of the electric traction options is based on electrification of the high density portions of the main Winnipeg Transit 1981 crosstown and downtown routes as shown in Exhibits 6.2, 6.3 and 6.4 in the main body of this report.

The electrified routes are:

1) Academy/Strafford/McGregor
2) Corydon/North Main
3) East Kildonan/Portage-Sturgeon Express-Portage Express
4) St. Mary's/Ellice
5) Mountain/Sargent
6) Osborne/Selkirk
7) Notre Dame/Logan
8) King's Park Express-Pembina University-Southwestern Corridor
9) Transcona/Eastern Corridor

Routes 1) - 7) follow current streets except for slight changes in the downtown area. Routes 8) and 9) follow the southwest and eastern corridors rather than current street routeways. The Portage Avenue segment of route 3) is electrified with double overhead conductors outside the downtown area to accommodate the express bus feature.

Three basic electric trolley system options are considered on these routes for determination of overhead and power distribution capital costs. These are:

Option 2 - A standard trolley coach system.

Option 3 - A trolley/diesel hybrid system slightly reduced in complexity due to the availability of vehicle offwire capability when operating in the diesel mode.

Option 4 - A trolley/flywheel system with only the wire necessary for flywheel recharging.

Options 2 and 3 could employ vehicles with or without regenerative braking but this feature does not significantly affect the capital costs of the overhead and power distribution systems.

## OPTION 2 - STANDARD TROLLEY COACH SYSTEM

Under this option the system is laid out such that all main routes are fully wired. Additionally, wire and turns are provided for pull-out/pull-in movements and to establish emergency routes. The bulk of the emergency capability would occur in the downtown area and on certain routes operating to the north and west of downtown.

This configuration results in approximately 109 electrified route kilometres (including double overhead lines on Portage Avenue). Costs are based on the employment of a feederless system in outlying areas and a feeder system in the downtown area. A feederless system involves a number of "smaller" AC/DC converter substations with only one overhead connection from each substation to the overhead conductors. It is most applicable to outlying areas of a radial system such as that of the City of Winnipeg. A typical station size of 500 kW is used for the feederless system.

A feeder type system consists of "larger" AC/DC stations with a number of connections (usually underground) from each station to the overhead lines. It is more practical in relatively dense areas such as the downtown core of Winnipeg where a number of the routes converge. A typical station size of 2000 kW is employed.

The system is laid out and the base cost is estimated under the assumption that existing poles would be reused where possible in the construction of the new system. The system base quantities are defined by determining the requirements for a totally new system and adjusting these requirements for the reuse of existing poles. Reusable poles are determined by liaison with the local utilities and are approximately 90% of the existing steel trolley poles and 50% of the existing wood poles now on the intended electrified routes. The total number of reusable poles will be approximately 900 units for this option.

System costs were determined by an examination of both forms of pole line construction - span construction and bracket arm construction. Span construction is the more prevalent form and involves suspension of the overhead trolley conductors from span wires across the streets. Bracket arm construction is generally more aesthetic and is more applicable in certain instances. Bracket arm construction involves suspension of the overhead trolley conductors directly from bracket arms on the poles and is most applicable on narrow two-way streets and on one-way streets since only one set of poles are required on the street. Bracket arm construction is also advantageous on extremely wide streets where span wires would tend to sag. Two sets of poles would be required in this case. A cost comparison between span and bracket construction is very dependent on individual circumstances but it is generally considered that on an overall system basis, the cost difference is very slight. Consequently, capital costs for span and bracket arm construction are considered equal for purposes of this study except that a system totally employing bracket construction would not allow for reuse of existing poles. The ultimate system would likely include both forms of construction as determined by specific circumstances.

Cost estimates for this system are outlined in Exhibit D-1.

**exhibit D-1**

## Capital Cost Estimate of Standard Trolley Coach System (1981 Dollars)

| | | | Totals (000) |
|---|---|---|---|
| 1. | Material-Overhead Conductors | | |
| | a) Spans | 3,660 x $60 ea. | $ 220 |
| | b) Pull Offs | 1,350 x $35 ea. | 47 |
| | c) Wire-Bronze | | |
| | 4/0 AWG | 457,200 m x $4.43/m | 2,025 |
| | 2/0 AWG | 24,400 m x $2.87/m | 70 |
| | d) Overhead Hardware | | |
| | Switches | 162 x $3,960 ea. | 642 |
| | Curve Segments | 609 x $ 660 ea. | 402 |
| | Cross Overs | 96 x $1,800 ea. | 173 |
| | Clamps | 16,500 x $ 15 ea. | 248 |
| | Hangers | 16,500 x $ 20 ea. | 330 |
| | e) Miscellaneous | | 600 |
| 2. | Labour-Overhead Conductors | | 12,350 |
| 3. | Material-Substations | | |
| | a) 2000 kW | 3 x $210,000 ea. | 630 |
| | b) 500 kW | 40 x $100,000 ea. | 4,000 |
| | c) Miscellaneous | | 360 |
| 4. | Labour-Substations | | |
| | a) Installation | 43 x $150,000 ea. | 6,450 |
| | b) Install Underground Conduit | 6,000 m x $315/m | 1,900 |
| | c) Land Acquisition | 22 lots x $20,000 ea. | 440 |
| | d) Miscellaneous | | 1,134 |
| 5. | Material and Labour - Poles | 6,420 x $1,400 ea. | 8,988 |
| | | | (10,248) |
| 6. | Engineering and Inspection | | 4,380 |
| | | | (4,226) |
| | Total | | $45,110 |
| | | | (46,495) |
| | Cost/Electrified Route km | | $414 |
| | | | (427) |

**NOTE:** Costs in parentheses denote system costs with no reuse of existing poles and are applicable for span or bracket arm construction.

**OPTION 3 - TROLLEY/DIESEL HYBRID SYSTEM**

For this option, wire is provided for all downtown routes including emergency capability, and for routes between downtown and the outer terminal, including terminal loops. Wire is not provided for pull-out/pull-in movements, branches to be operated in the diesel mode, and emergency routes outside of the downtown area. Approximately 101 electrified route kilometres are required under this option (including double overhead lines on Portage Avenue).

The remaining design criteria are essentially the same as those for Option 2.

Cost estimates are provided in Exhibit D-2.

**OPTION 4 - TROLLEY/FLYWHEEL SYSTEM**

Under this option, two-way wire is provided in 0.8 kilometre stretches in various locations throughout the system for running charging and 0.4 kilometre sections of one-way wire are provided at the termination points of the routes in 10 locations for at-rest charging. The 0.8 kilometre sections are located every 3-5 kilometres along each of the routes, as well as at the points where each route leaves the downtown area. Double overhead lines are allowed for the sections on Portage Avenue. This results in 35 - 0.8 kilometre sections of two-way wire and 10 - 0.4 kilometre sections of one-way wire at various locations throughout the system as shown in Exhibit 6.4 in the main body of this report.

A typical substation size of 500 kW is utilized for each wired segment, except the Portage/Broadway and Donald/Main segments which can share common substations. It should be noted that substation sizes in this case can be significantly affected by flywheel coach operating characteristics.

The remaining design criteria for this option are essentially the same as for Options 2 and 3 except that only approximately 200 existing poles would be reusable under this option.

Cost estimates for this system are outlined in Exhibit D-3.

## exhibit D-2

## Capital Cost Estimate of Trolley/Diesel System (1981 Dollars)

| | | | Totals (000) |
|---|---|---|---|
| 1. | Material-Overhead Conductors | | |
| | a) Spans | 3,370 x $60 ea. | $ 202 |
| | b) Pull Offs | 1,100 x $35 ea. | 39 |
| | c) Wire-Bronze | | |
| | 4/0 AWG | 422,100 m x $4.43/m | 1,870 |
| | 2/0 AWG | 24,400 m x $2.87/m | 70 |
| | d) Overhead Hardware | | |
| | Switches | 72 x $3,960 ea. | 285 |
| | Curve Segments | 444 x $ 660 ea. | 293 |
| | Cross Overs | 96 x $1,800 ea. | 173 |
| | Clamps | 15,300 x $ 15 ea. | 230 |
| | Hangers | 15,300 x $ 20 ea. | 306 |
| | e) Miscellaneous | | 540 |
| 2. | Labour-Overhead Conductors | | 10,420 |
| 3. | Material-Substations | | |
| | a) 2000 kW | 3 x $210,000 ea. | 630 |
| | b) 500 kW | 35 x $100,000 ea. | 3,500 |
| | c) Miscellaneous | | 360 |
| 4. | Labour-Substations | | |
| | a) Installation | 38 x $150,000 ea. | 5,700 |
| | b) Install Underground Conduit | 6,000 m x $315/m | 1,900 |
| | c) Land Acquisition | 19 lots x $20,000 ea. | 380 |
| | d) Miscellaneous | | 1,044 |
| 5. | Material and Labour - Poles | 5,840 x $1,400 ea. | 8,176 (9,436) |
| 6. | Engineering and Inspection | | 3,612 (3,737) |
| | **Total** | | 39,730 (41,115) |
| | Cost/Electrified Route km | | 393 (407) |

**NOTE:** Costs in parentheses denote system costs with no reuse of existing poles and are applicable for span or bracket arm construction.

**exhibit D-3**

## Capital Cost Estimate of Trolley/Flywheel System (1981 Dollars)

| | | | Totals (000) |
|---|---|---|---|
| 1. | Material-Overhead Conductors | | |
| | a) Spans | 1,050 x $60 ea. | $ 63 |
| | b) Wire-Bronze 4/0 AWG | 120,700 m x $4.43/m | 535 |
| | c) Overhead Hardware | | |
| | Clamps | 4,450 x $ 15 ea. | 67 |
| | Hangers | 4,450 x $ 20 ea. | 89 |
| | d) Miscellaneous | | 140 |
| 2. | Labour-Overhead Conductors | | 2,320 |
| 3. | Material-Substations | | |
| | a) 500 kW | 43 x $100,000 ea. | 4,300 |
| | b) Miscellaneous | | 430 |
| 4. | Labour-Substations | | |
| | a) Installation | 43 x $150,000 ea. | 6,450 |
| | b) Land Acquisition | 22 lots x $20,000 ea. | 440 |
| | c) Miscellaneous | | 944 |
| 5. | Material and Labour - Poles | 1,900 x $1,100 ea. | 2,090 |
| | | | (2,310) |
| 6. | Engineering and Inspection | | 1,787 |
| | | | (1,809) |
| | Total | | 19,655 |
| | | | (19,897) |

**NOTE:** Costs in parentheses denote system costs with no reuse of existing poles and are applicable for span or bracket arm construction.

**ESTIMATING CRITERIA**

The following parameters were used to cost the overhead wire systems:

1. Material-Overhead Conductors

All figures based on recent prices and hardware from Ohio Brass and Canada Wire.

a) Span - Installation every 30 m of electrified route kilometre plus 10% contingency for special supports.

b) Pull Off - 2 pull offs per curve segment
3 pull offs per switch.

c) Wire - It is assumed that 4/0 AWG bronze wire would be installed outside the downtown area to provide the greater conductivity required in a feederless system. 2/0 AWG wire is used in the downtown area. The amounts shown are based on four conductors per kilometer of fully electrified route with 10% contingency for non-straight runs. Prices are from Canada Wire.

d) Overhead Hardware - The quantities are based on the total wire miles required for the intended routes. The prices are recent quotes from Ohio Brass, the equipment supplier for all present Canadian transit systems.

e) Miscellaneous - Covers all materials not included above, such as span wire insulators and so forth.

2. Labour-Overhead Conductors

Total labour charges are a factor of 2.6 of total overhead material based on a typical factor of 1.25 times

material when poles are taken into account. Sources are local utilities and contractors and the City of Vancouver.

3. Material-Substations

The prices are based on Seattle and Vancouver experience and recent quotes and discussions with suppliers. Total capacity required is based on the standard diversity curve. No growth factor was employed to balance the power savings possible from chopper propulsion units. Miscellaneous costs include cables and ducts.

4. Labour-Substations

Labour charges are based on Seattle and Vancouver recent experiences with costs inflated to 1981 dollars. Since installation costs are very site-dependent, an allowance has been made for land acquisition costs under the assumption that half of the stations will require purchase of a standard residential size lot. Additionally it was assumed that 6,000 m of underground conduit would be required in the downtown area at an installation cost of approximately $315/m interconecting cable installations and an allowance of $8,000 per substation to cover costs for provision of AC power for work that would not be done by utilities. Capital cost contributions to the local utilities are not included since Winnipeg Hydro has indicated these costs (approximately $2,000,000) would not be charged to Transit since Transit would be billed according to the standard power service rate and these costs would be recovered from revenue.

5. Poles

The number of poles is the net number of new poles required after deduction of useable existing poles on the

routes. The use of anchor base steel poles is assumed in all new areas as they are visually less obtrusive than wood poles and the new areas are in suburban type locations. The average cost is based on recent Vancouver experiences and discussions with utilities, and is determined to be $1,400 (installed) for Options 2 and 3 and $1,100 for Option 4. The average pole unit costs for Option 4 can be reduced due to structural loading since no high strength poles would be required as there is no need for support of cross-overs, pull-offs and other "special" work.

6. Engineering and Inspection

This amount is set at 10% of the cost allocated in items 1 through 5.

## OPERATING COSTS

Operating costs are subdivided as follows:

A. Trolley Coach Maintenance Costs

Trolley coach maintenance costs are determined from most recent City of Vancouver and American experiences corrected for Winnipeg conditions and escalated to 1981 dollars. They are estimated at 19 cents per vehicle kilometer. This figure includes normal fleet servicing (motors, electrical, tires, etc.) but does not include vehicle depreciation.

B. Overhead Line Maintenance Costs

Annual overhead line maintenance costs for the system are as follows:

| | | |
|---|---|---|
| Options 2 and 3 | - | $1,063,000 |
| Option 4 | - | 289,000 |

These costs are determined by calculating personnel and equipment requirements to maintain a new system according to the Urban Mass Transportation Administration June 1980 report and utilizing Winnipeg 1981 labour rates.

C. Electrical Energy Costs

Annual electrical energy costs for each of the options are estimated as follows:

| | |
|---|---|
| Option 2A - Standard Trolley - no regeneration | $1,203,000 |
| 2B - Standard Trolley - regeneration | 972,000 |
| 3A - Trolley/Diesel - no regeneration | 1,201,000 |
| 3B - Trolley/Diesel - regeneration | 982,000 |
| 4 - Trolley/Flywheel | 1,562,000 |

These costs are based on Winnipeg Hydro Power Standard Rates (1981) for primary power of $4.30 per kVA (demand) and $0.0112 per kWh (consumption). These are conservative costs since the ultimate rates would be determined by negotiation between Winnipeg Transit and the supplying utilities - Winnipeg and Manitoba Hydro.

## 1987 TROLLEY COACH SYSTEM ALTERNATIVES

The initial trolley route systems outlined in Exhibits 9.2 through 9.5 are costed in a manner similar to the electric trolley options. The initial trolley route systems are:

Alternative 1 Corydon/North Main, East Kildonan/Polo Park, Osborne/Selkirk - 40.5 electrified route kilometres.

Alternative 2 Corydon North Main, East Kildonan/Polo Park, 27.5 electrified route kilometres.

Alternative 3 Corydon/North Main, Pembina - 30.5 electrified route kilometres.

Alternative 4 East Kildonan/Polo Park, Pembina - 34 electrified route kilometres.

The cost estimates for these alternatives are determined using the same design and estimating criteria as for the electric trolley options with the following exceptions:

- The downtown substation size for initial systems of this type and configuration is chosen at 1000 kW due to the reduced energy requirements and reduced downtown routing. In addition, only 2,000 metres of underground conduit would be required in the downtown area.
- Existing poles are assumed to be reused wherever possible. The number of poles is the net number of new poles required.
- Wiring is included for two garages in each alternative rather than for a total of three garages in the total system of Option 2.

Cost estimates for these alternatives are outlined in Exhibits D-4 through D-7.

Operating Costs

Operating costs are also determined utilizing the same criteria as for Option 2. Consequently trolley coach maintenance costs are identical at 19¢ per vehicle kilometre.

Annual overhead line maintenance costs are estimated at $289,000 for all four alternatives in that the same basic crew size and maintenance truck fleet would be required.

Annual electrical energy costs for each of the alternatives are estimated as follows:

| | |
|---|---|
| Alternative 1: | $285,000 |
| Alternative 2: | 230,000 |
| Alternative 3: | 253,000 |
| Alternative 4: | 259,000 |

These costs assume that regenerative braking would be used in the initial system.

## exhibit D-4

## Alternative 1
## Capital Cost Estimate (1981 Dollars)

| | | | Totals (000) |
|---|---|---|---|
| 1. | Material-Overhead Conductors | | |
| | a) Spans | 1,450 x $60 ea. | $ 87 |
| | b) Pull Offs | 550 x $35 ea. | 19 |
| | c) Wire-Bronze | | |
| | 4/0 AWG | 154,400 m x $4.43/m | 684 |
| | 2/0 AWG | 13,800 m x $2.87/m | 40 |
| | d) Overhead Hardware | | |
| | Switches | 77 x $3,960 ea. | 305 |
| | Curve Segments | 260 x $ 660 ea. | 172 |
| | Cross Overs | 44 x $1,800 ea. | 79 |
| | Clamps | 5,800 x $ 15 ea. | 87 |
| | Hangers | 5,800 x $ 20 ea. | 116 |
| | d) Miscellaneous | | 280 |
| 2. | Labour-Overhead Conductors | | 4,860 |
| 3. | Material-Substations | | |
| | a) 1000 kW | 2 x $141,000 ea. | 282 |
| | b) 500 kW | 9 x $100,000 ea. | 900 |
| | c) Miscellaneous | | 83 |
| 4. | Labour-Substations | | |
| | a) Installation | 11 x $150,000 ea. | 1,650 |
| | b) Install Underground Conduit | 2,000 m x $315/m | 630 |
| | c) Land Acquisition | 5 lots x $20,000 ea. | 100 |
| | d) Miscellaneous | | 255 |
| 5. | Material and Labour - Poles | 2,176 x $1,400 ea. | 3,046 |
| 6. | Engineering and Inspection | | 1,367 |
| | **Total** | | 15,042 |
| | Cost/Electrified Route km | | $ 371 |

**NOTE:** System costs allow for reuse of existing poles where possible.

**exhibit D-5**

**Alternative 2**
**Capital Cost Estimate (1981 Dollars)**

| | | | Totals (000) |
|---|---|---|---|
| 1. | Material-Overhead Conductors | | |
| | a) Spans | 990 x $60 ea. | $ 59 |
| | b) Pull Offs | 370 x $35 ea. | 13 |
| | c) Wire-Bronze | | |
| | 4/0 AWG | 106,800 m x $4.43/m | 473 |
| | 2/0 AWG | 8,750 m x $2.87/m | 25 |
| | d) Overhead Hardware | | |
| | Switches | 56 x $3,960 ea. | 222 |
| | Curve Segments | 183 x $ 660 ea. | 121 |
| | Cross Overs | 32 x $1,800 ea. | 58 |
| | Clamps | 3,960 x $ 15 ea. | 59 |
| | Hangers | 3,960 x $ 20 ea. | 79 |
| | d) Miscellaneous | | 200 |
| 2. | Labour-Overhead Conductors | | 3,390 |
| 3. | Material-Substations | | |
| | a) 1000 kW | 2 x $141,000 ea. | 282 |
| | b) 500 kW | 6 x $100,000 ea. | 600 |
| | c) Miscellaneous | | 62 |
| 4. | Labour-Substations | | |
| | a) Installation | 8 x $150,000 ea. | 1,200 |
| | b) Install Underground Conduit | 2,000 m x $315/m | 630 |
| | c) Land Acquisition | 4 lots x $20,000 ea. | 80 |
| | d) Miscellaneous | | 200 |
| 5. | Material and Labour - Poles | 1,410 x $1,400 ea. | 1,974 |
| 6. | Engineering and Inspection | | 973 |
| | **Total** | | 10,700 |
| | Cost/Electrified Route km | | $ 389 |

**NOTE:** System costs allow for reuse of existing poles where possible.

**exhibit D-6**

**Alternative 3**
**Capital Cost Estimate (1981 Dollars)**

| | | | Totals (000) |
|---|---|---|---|
| 1. | Material-Overhead Conductors | | |
| | a) Spans | 1,100 x $60 ea. | $ 66 |
| | b) Pull Offs | 400 x $35 ea. | 14 |
| | c) Wire-Bronze | | |
| | 4/0 AWG | 127,500 m x $4.43/m | 565 |
| | 2/0 AWG | 13,500 m x $2.87/m | 39 |
| | d) Overhead Hardware | | |
| | Switches | 61 x $3,960 ea. | 242 |
| | Curve Segments | 202 x $ 660 ea. | 133 |
| | Cross Overs | 35 x $1,800 ea. | 63 |
| | Clamps | 4,400 x $ 15 ea. | 66 |
| | Hangers | 4,400 x $ 20 ea. | 88 |
| | d) Miscellaneous | | 230 |
| 2. | Labour-Overhead Conductors | | 3,920 |
| 3. | Material-Substations | | |
| | a) 1000 kW | 2 x $141,000 ea. | 282 |
| | b) 500 kW | 7 x $100,000 ea. | 700 |
| | c) Miscellaneous | | 69 |
| 4. | Labour-Substations | | |
| | a) Installation | 9 x $150,000 ea. | 1,350 |
| | b) Install Underground Conduit | 2,000 m x $315/m | 630 |
| | c) Land Acquisition | 4 lots x $20,000 ea. | 80 |
| | d) Miscellaneous | | 225 |
| 5. | Material and Labour - Poles | 1,710 x $1,400 ea. | 2,394 |
| 6. | Engineering and Inspection | | 1,116 |
| | **Total** | | 12,272 |
| | Cost/Electrified Route km | | $ 402 |

**NOTE:** System costs allow for reuse of existing poles where possible.

## exhibit D-7

## Alternative 4
## Capital Cost Estimate (1981 Dollars)

| | | | Totals (000) |
|---|---|---|---|
| 1. | Material-Overhead Conductors | | |
| | a) Spans | 1,230 x $60 ea. | $ 74 |
| | b) Pull Offs | 460 x $35 ea. | 16 |
| | c) Wire-Bronze | | |
| | 4/0 AWG | 151,500 m x $4.43/m | 669 |
| | 2/0 AWG | 12,400 m x $2.87/m | 36 |
| | d) Overhead Hardware | | |
| | Switches | 67 x $3,960 ea. | 265 |
| | Curve Segments | 223 x $ 660 ea. | 147 |
| | Cross Overs | 38 x $1,800 ea. | 68 |
| | Clamps | 4,920 x $ 15 ea. | 74 |
| | Hangers | 4,920 x $ 20 ea. | 98 |
| | d) Miscellaneous | | 260 |
| 2. | Labour-Overhead Conductors | | 4,430 |
| 3. | Material-Substations | | |
| | a) 1000 kW | 2 x $141,000 ea. | 282 |
| | b) 500 kW | 8 x $100,000 ea. | 800 |
| | c) Miscellaneous | | 76 |
| 4. | Labour-Substations | | |
| | a) Installation | 10 x $150,000 ea. | 1,500 |
| | b) Install Underground Conduit | 2,000 m x $315/m | 630 |
| | c) Land Acquisition | 5 lots x $20,000 ea. | 100 |
| | d) Miscellaneous | | 230 |
| 5. | Material and Labour - Poles | 2,020 x $1,400 ea. | 2,828 |
| 6. | Engineering and Inspection | | 1,258 |
| | **Total** | | 13,841 |
| | Cost/Electrified Route km | | $ 407 |

**NOTE:** System costs allow for reuse of existing poles where possible.

# APPENDIX E

# ALCOHOL FUELS

## ALCOHOL FUELS

Recent oil shortages have invoked a great amount of interest in alcohol fuels in North America and elsewhere. The two alcohols most commonly considered for extending or replacing petroleum-based fuel are methanol and ethanol. Although methanol is presently being manufactured from natural gas, biomass-derived methanol is considered more appropriate for long-term supply. Ethanol can be produced from sugar crops, grains, biomass and cellulosic waste materials. The following scenarios have been considered for the long-term supply of these fuels:

- Ethanol from wood
- Methanol from wood
- Ethanol from municipal waste.

Capital and operating costs have been estimated and financial analyses performed in each case to project prices over the period 1985-2000.

## METHOD OF FINANCIAL ANALYSIS AND GENERAL ASSUMPTIONS

Plant costs were obtained from published data from several sources including "Feasibility of Liquid Fuels from Renewable Sources" by Inter Group Consulting Economists (the Intergroup Report). These costs were established at different times and must be adjusted to the same time base for real comparison. We established 1985 as the base year and all costs have been adjusted to reflect this.

Cost indexes for labour, electricity, natural gas, construction cost and general price levels were obtained and extrapolated to 1985. Capital and operating costs were adjusted to the base year using these indexes:

- labour was based on Statistics Canada average weekly earnings in Winnipeg using 1977 as the base year and extrapolated to 1985;
- electricity was based on Manitoba Hydro rates to 1979 (prior to the price freeze) extrapolated to 1985. Thus the effect of the price freeze on long-term hydro costs was neglected;

- natural gas was calculated based on the "Alberta Border Price" plus transportation to Winnipeg, the Federal Natural Gas Tax, and a distribution charge. The Alberta Border Price is fixed by the recent Federal-Alberta Agreement. The Natural Gas Tax can change, however, and we have used values from the Manitoba Department of Energy, Mines and Resources. Transportation and distribution charges are based on present values inflated at 10%;

- construction cost was based on the Southam Composite Construction Index from 1970 to 1981 and extrapolated to 1985.

The use of indexes permitted the price for each component to be projected to the base year (1985) from the most recent data available.

All energy intensive components were escalated at 3% greater than inflation to show the expected real increase in energy costs. These components include power, wood feedstock, chemicals and distribution costs.

The cost of wood feedstock was assumed at $35/oven dry tonne in 1981 escalated at 15% per year giving a price of $61.22 in 1985 for both methanol and ehtanol production.

Total production costs were calculated in 1985 dollars and these costs were inflated at 12% to provide costs in current dollars. These costs were adjusted to gasoline equivalent.

## PROCESS SPECIFIC ASSUMPTIONS

There are several assumptions which are specific to the process being analyzed.

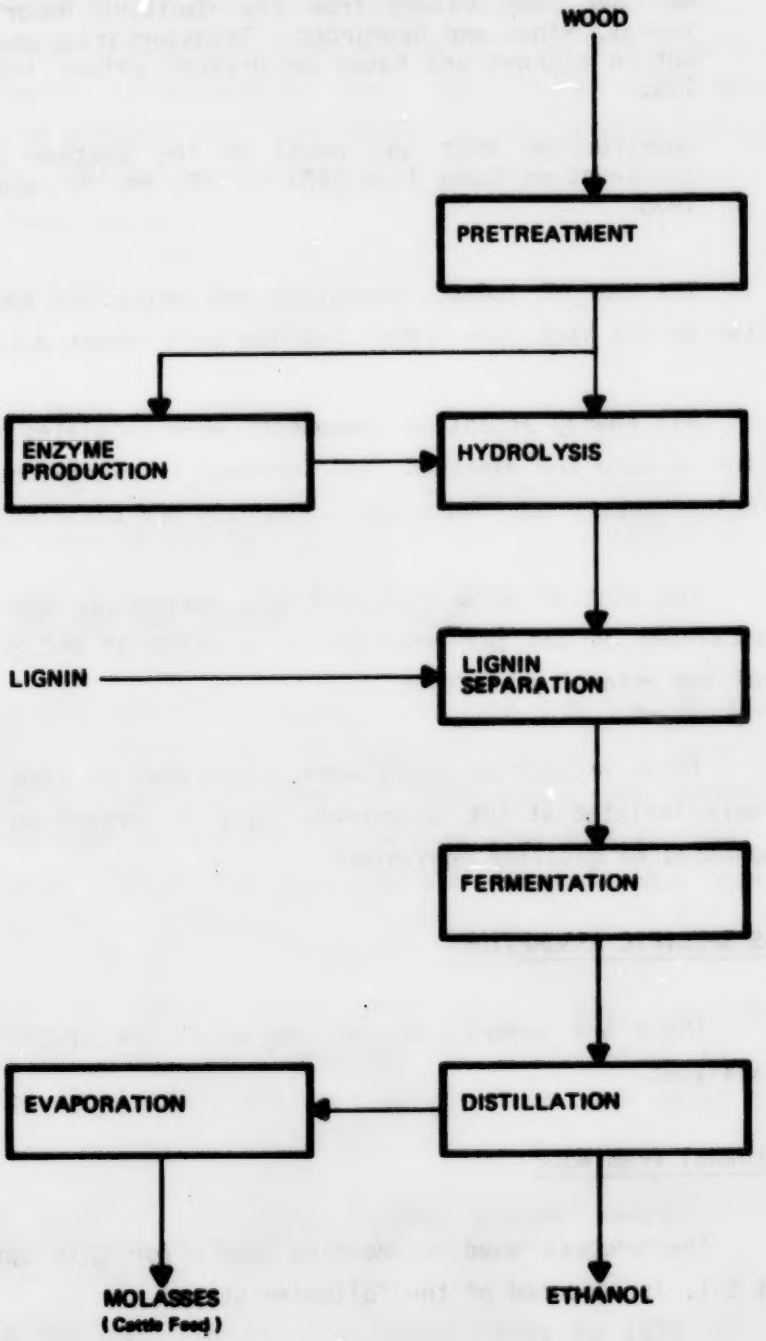
### Ethanol from Wood

The process used to develop costs for this option, as shown in Exhibit E-1, is composed of the following steps:

- pretreatment;
- enzymatic hydrolysis;

**exhibit E-1**

**Ethanol Production from Wood**



- lignin extraction;
- fermentation;
- distillation to anhydrous ethanol;
- evaporation of stillage to molasses.

The plant, located in Manitoba, will produce 135 million litres of ethanol per year. Capital cost is estimated at $129.9 million in 1985, and annual operating cost at $41.9 million. Whole stillage will be evaporated to molasses for cattle feed and lignin will be sold for chemical or pharmaceutical use.

The feedstock for the plant will be Aspen or similar hardwood using whole tree harvesting. Aspen plantations could be available by the later stages of the program. The plant will be located in the interlake or south eastern Manitoba.

The plant will be privately owned and operated with a return on investment of 10% before taxes and before inflation. Capital will be returned over 20 years. To establish sensitivity, the cost of wood feedstock was increased by 50% to establish the upper limit for the alcohol price range.

We believe that the technology for producing ethanol from wood is well established, and commercial-scale demonstration is expected in Canada by 1983. Commercial production could commence by 1985, although a number of factors could delay such production.

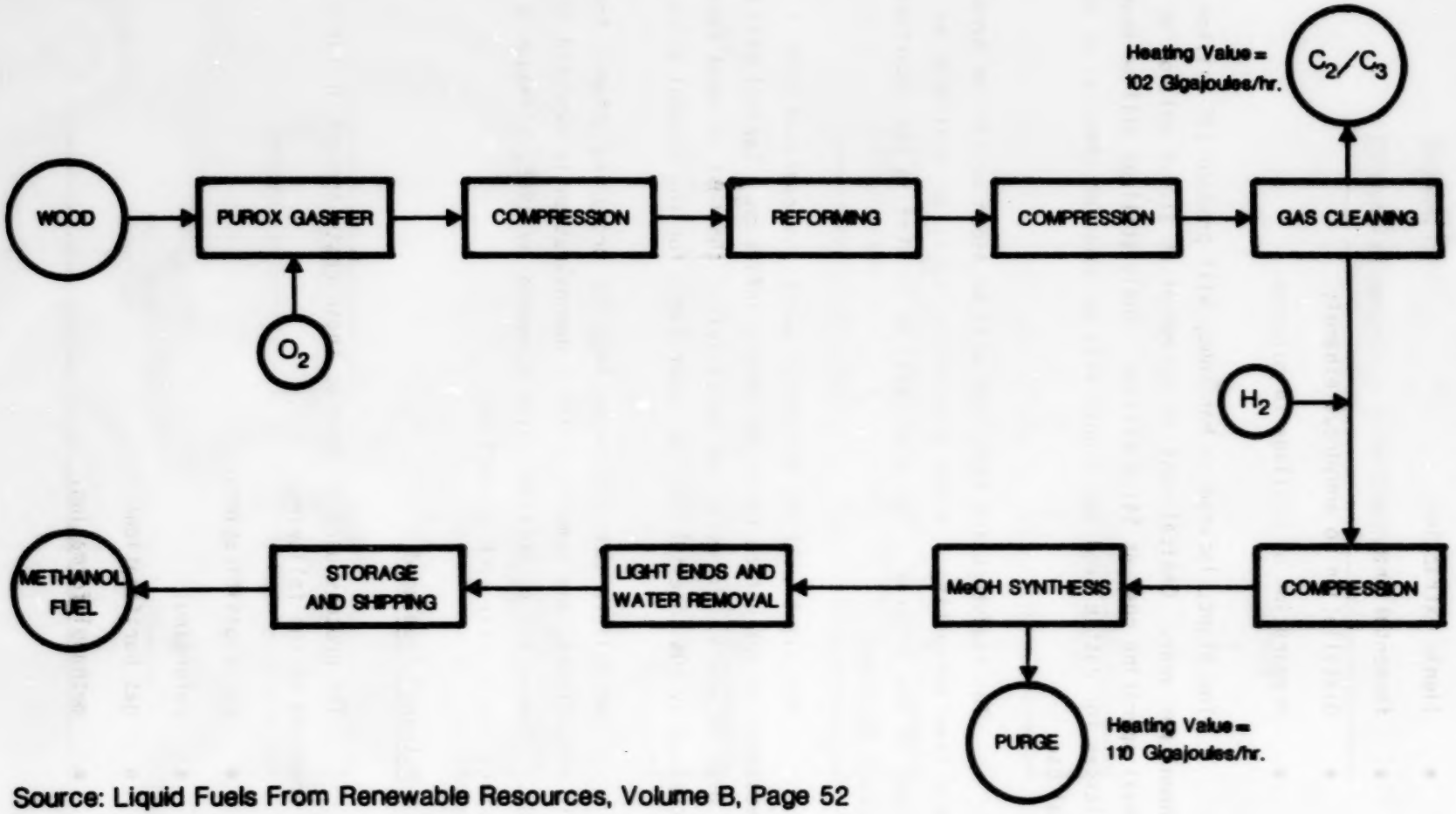
Methanol from Wood

The process used to develop these costs appears in Exhibit E-2 and is composed of the following:

- Purox gasifications;
- reforming;
- gas purification;
- methanol formation.

**exhibit E-2**

**Simplified Block Diagram of a 1,100 Ton/Day Methanol Plant with Purox Gasification of Wood and Import of Merchant Hydrogen and Oxygen**




Source: Liquid Fuels From Renewable Resources, Volume B, Page 52

The plant will produce 330,000 tonnes per year of fuel grade methanol. All rejected gas and purge gas is burned as fuel for the process with additional power supplied by natural gas. Other feedstocks could be used including lignite and peat but all costs are based on wood feedstock.

The plant will be operated as a private venture with 10% return on investment before taxes and before inflation. The capital cost is estimated at $286.7 million in current dollars in 1985. Estimated annual operating cost is $93.9 millions in 1985. Feedstock can be any wood waste or whole tree harvesting and the plant should be located near a source of wood waste. The type of wood makes no difference to this process.

The technology of this process is well established based on other feedstocks and requires very little development except in wood gasification, for which a commercial demonstration is desirable.

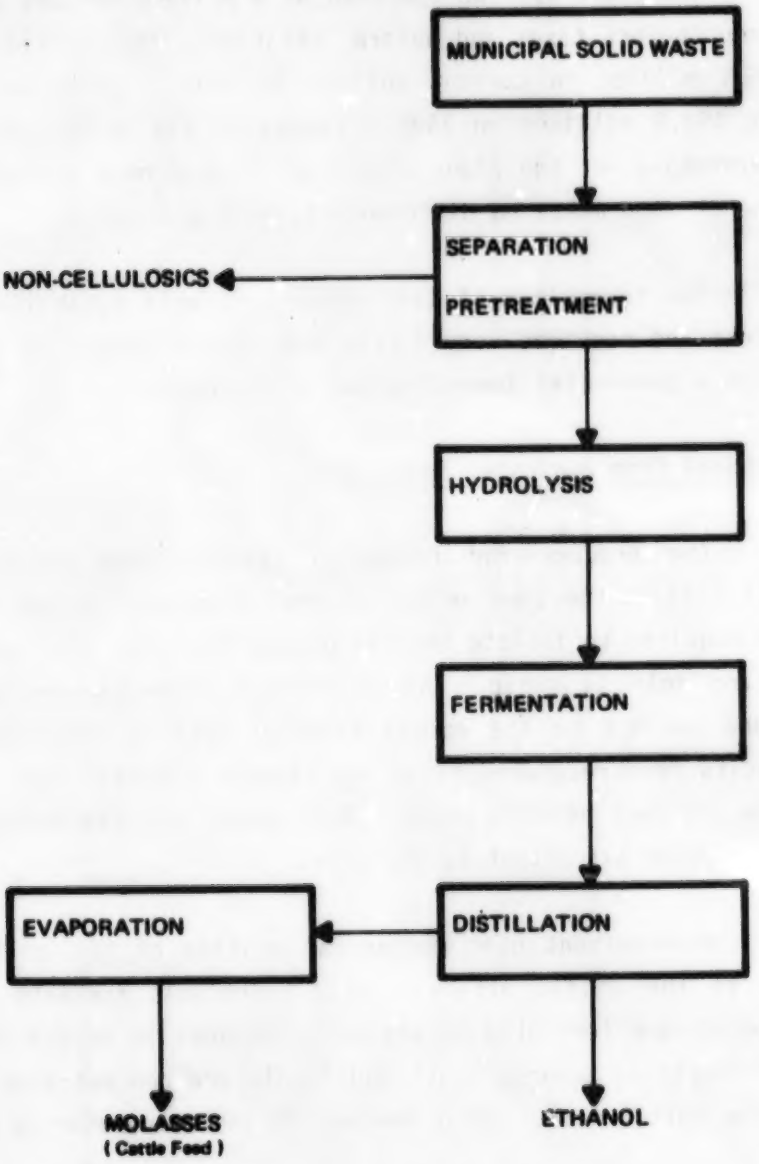
Ethanol from Municipal Solid Waste

The process for producing ethanol from municipal solid waste (Exhibit E-3) is the same as for ethanol from wood except a separation process is required to isolate the cellulosic fraction. Ferrous metals are separated and sold as scrap. Non-cellulosic organics are burned to provide heat, and savings on the normal disposal cost is credited to the process. The credits from recovered scrap and reduced disposal cost are approximately equal to the cost of separation. This means that the cellulose feedstock is available at no extra cost to the City.

Pretreatment uses mechanical milling of the cellulose leaving it exposed to the acidic attack. Acid hydrolisis converts the cellulose to sugars which are fermented to ethanol. Ethanol is separated by distillation and the remaining sugars, yeast and lignin are concentrated in an evaporator for use as cattle feed. Water removed in the evaporator is discharged to the sewer.

**exhibit E-3**

**Ethanol from Municipal Solid Waste**



The plant would be owned and operated by the City and the product would be used as fuel for City equipment and vehicles. The capital cost of $77.00 million (1985) dollars would be financed at 6% return on investment before taxes and before inflation. Estimated annual operating cost is $10.1 million in 1985.

The feedstock would be derived from solid waste from the inner city only (489 tonnes/day) and could be augmented from other districts as required. The plant will be located at or near the existing incinerator to provide minimum transportation of waste. The feedstock would be mostly paper and so will require minimal pretreatment but will produce less byproduct than wood feedstock.

The technology is fairly recent and has not yet been run on a continuous pilot scale. Full scale demonstration, specially in acid hydrolisis is required before a commercial plant can be constructed.

## RESULTS AND DISCUSSIONS

The following prices, expressed in 1985 dollars per unit of alcohol, equivalent to a litre of gasoline, have been determined for the three cases:

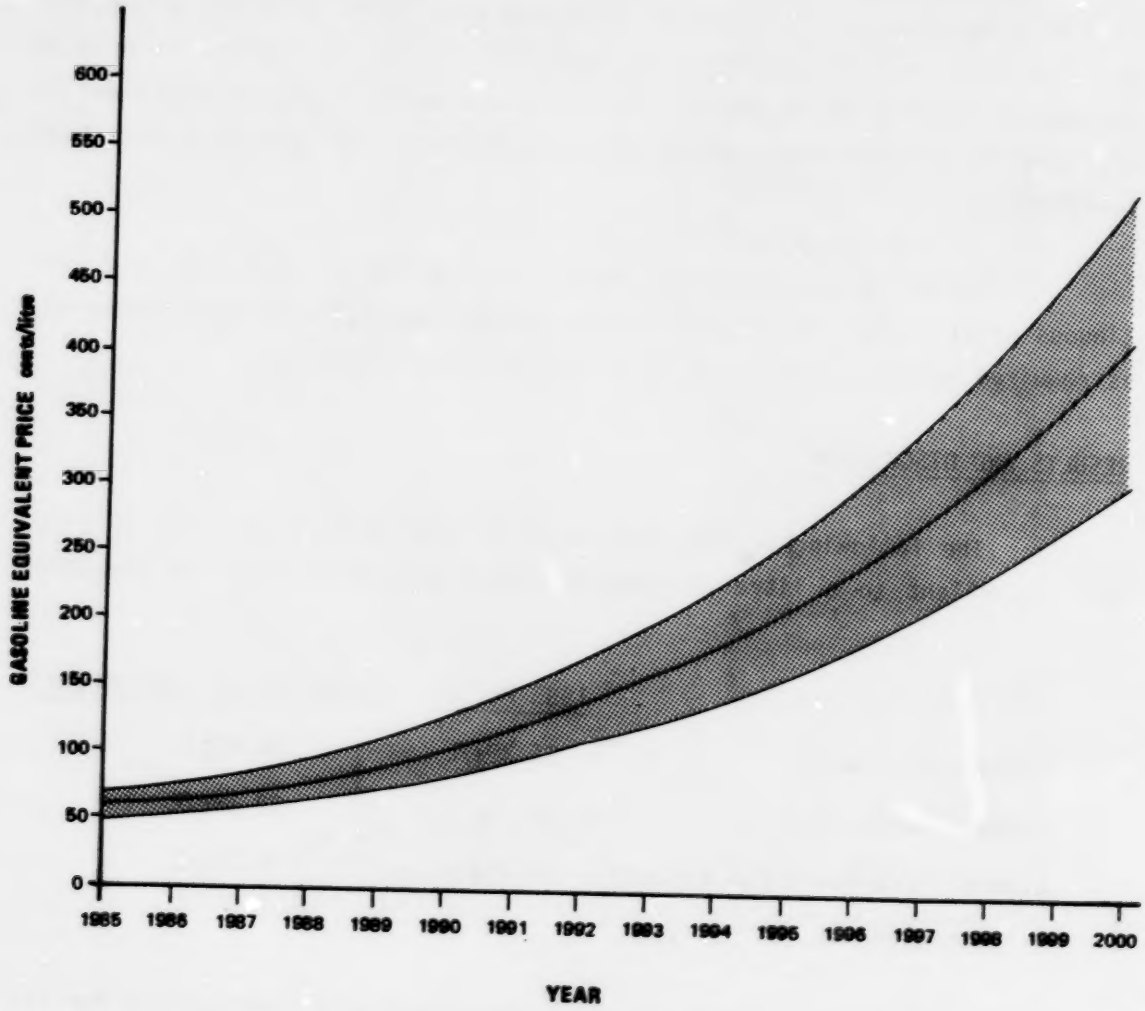
| | 1985 PRICES | EXPRESSED IN 1981 DOLLARS* |
|---|---|---|
| Ethanol from Wood | = 65.30¢/L | 44.60¢/L |
| Methanol from Wood | = 47.11¢/L | 32.18¢/L |
| Ethanol from Municipal Wastes | = 44.28¢/L | 30.24¢/L |

* Discounted at 10% per year.

Exhibit E-4 presents gasoline equivalent price projections for the three scenarios for years 1985 to 2000.

**exhibit E-4**

**Alcohol Fuel Price Projection**



1. The low-cost curve is for ethanol from municipal wastes, based on assumptions discussed previously. This is considered to be the most optimistic case. Major reasons for low cost for this scenario is the "free" availability of substrate. If the costs of separating cellulosic wastes are higher than expected, the price could increase substantially.

2. The top curve presents a highly pessimistic case, in which ethanol from wood scenario costs have been projected using wood costs 50 percent higher than estimated.

3. The middle curve is an average of the optimistic and the pessimistic cases, and corresponds closely to methanol production from wood.

For a municipality with a solid waste disposal problem, the idea of converting such waste to fuel for our use has great attraction. We recommend that costs for ethanol from municipal wastes be used for comparison of various fuels. However, level of accuracy of these costs, and technology status must be defined to put these costs in proper perspective.

## CONCLUSIONS

We conclude that:

- methanol and ethanol are potential fuels for transit vehicles in Winnipeg;
- costs of producing ethanol from municipal wastes are low and the concept should be attractive to a municipality;
- technology, specially acid hydrolysis, to convert cellulosic fraction of municipal waste to ethanol must be demonstrated on an industrial scale before commercialization;
- the uncertainties in projecting costs of a process not yet demonstrated should be kept in mind if ethanol from municipal waste is competitive with options other than alcohol fuels.

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